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ABSTRACT
Objective: Evolving production practices in the swine industry may alter the working environment. This research characterized the influence of stall versus pen gestation housing and wet versus dry feed in finishing on air contaminant concentrations. Methods: Eight-hour time-weighted ammonia, hydrogen sulfide, respirable dust, respirable endotoxin, and carbon dioxide concentrations and temperature were measured regularly at stationary locations throughout a year in a facility with parallel gestation stall and open pen housing and parallel finishing rooms using dry and wet feed delivery systems. Hazard indices were calculated using ammonia, hydrogen sulfide, and endotoxin concentrations and relevant occupational exposure limits. Statistical analyses were performed to assess the influence of time of year, housing, and feed on measured parameters. Results: Due to reductions in ventilation rates as outdoor temperatures decreased, season affected pollutant levels more than other factors, with concentrations approximately one order of magnitude greater in winter than during summer. Ammonia, dust, and endotoxin were 25%, 43%, and 67% higher, respectively, on average, in the room with gestation pens than in the room with stalls. Endotoxin concentrations were more than five times higher, on average, with the dry feed system than with wet feed. While individual contaminant concentrations were generally below regulatory limits, hazard index calculations suggest that the effects of combined exposures on respiratory health may present a risk to workers. Elevated levels of respirable endotoxin and hydrogen sulfide were observed during power washing. Conclusions: Ventilation changes in response to seasonal requirements influenced air contaminant concentrations more than production practices, especially housing type. Wet feed systems substantially reduced airborne endotoxin concentrations.

KEYWORDS
Air pollutants; feeding systems; gestation housing; swine; workers

Introduction

Airway diseases have been linked to work in swine barns, including occupational asthma, chronic bronchitis, chronic obstructive pulmonary disease (COPD), mucous membrane irritation, organic dust toxic syndrome, and hypersensitivity pneumonitis.[1] Decreased pulmonary function, both over a work shift and over a lifetime, have also been noted among these workers.[2,3]

Many environmental air pollutants that may contribute to respiratory illness are present in swine confinement buildings, including ammonia (NH_3), hydrogen sulfide (H_2S), carbon dioxide (CO_2), total and respirable dust, and endotoxin.[4–6] Permissible exposure limits (PELs) from the Occupational Safety and Health Administration (OSHA),[7] recommended exposure limits (RELs) from the National Institute for Occupational Safety and Health (NIOSH),[7] and threshold limit values (TLVs) from the American Conference of Governmental Industrial Hygienists (ACGIH)[8] are shown in Table 1. The PELs are regulatory limits in the U.S. whereas the RELs and TLVs are guidelines for best practice. For swine workers, Reynolds et al.[9] suggested exposure limits of 2.5 mg/m^3 for total dust and 7.5 ppm for NH_3. Donham et al.[10] recommended similar limits for poultry workers. NH_3, H_2S, dust, and endotoxin are all known respiratory irritants that may act together to influence worker health. A study conducted with poultry workers indicated that dust and NH_3 likely work synergistically to produce adverse respiratory health effects.[11]

No TLVs or regulatory limits have been established for airborne endotoxin. Donham et al.[4] observed significant decrements in pulmonary function tests

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Table 1. Occupational exposures limits for ammonia, hydrogen sulfide, carbon dioxide, and respirable particles. All values are 8-hour time-weighted averages unless the designation (C) is present, in which case there is no 8-hour limit and the value presented is a ceiling limit. No NIOSH recommended exposure limit exists for respirable particles.

Pollutant	OSHA Permissible Exposure Limit (PEL)	NIOSH Recommended Exposure Limit (REL)	ACGIH Threshold Limit Value (TLV)
Ammonia	50 ppm	25 ppm	25 ppm
Hydrogen sulfide	20 ppm (C)	10 ppm (C)	1 ppm
Carbon dioxide	5,000 ppm	5,000 ppm	5,000 ppm
Respirable particles	5 mg/m^3		3 mg/m^3

among swine workers exposed to endotoxin concentrations of about 900 endotoxin units (EU)/m^3. Post et al.[12] found that workers exposed to endotoxin concentrations greater than 200 EU/m^3 in grain dust had greater risk of a decline in FEV1 (forced expiratory volume in 1 s). A Dutch expert committee proposed a health-based recommended occupational exposure limit (HBROEL) of 90 EU/m^3 over an 8-hour time-weighted average for a worker exposed over a 40-year work career.[13]

Several factors contribute to worker exposure to these air pollutants. Seasonality plays a role in exposures, with elevated concentrations of most of the aforementioned air pollutants during colder months, when farms reduce ventilation to maintain heat in the buildings.[14–17] Manure systems factor into pollutant levels: slatted deep-pit manure systems with mechanical ventilation are associated with higher concentrations of NH_3 and H_2S than other systems.[18] Dust concentrations are higher as the total mass of pigs in a room increases and when pigs are more active.[19,20]

In the swine industry currently, gestating sows are predominantly housed in individual stalls that restrict movement. In response to concerns about animal welfare, the industry is transitioning to greater use of group housing, where sows reside in large pens and share feeding and water systems. After analyzing 354 personal exposure measurements for Danish swine workers, Basinas et al.[21] were unable to detect statistically significant differences in dust or endotoxin exposures between workers in facilities with pens and those in operations with stalls.

Feeding systems have the potential to influence air contaminant concentrations. Some facilities have installed liquid feed systems that utilize high-moisture corn and other byproducts of the corn and food industries in place of traditional dry grain feed. Exposures to dust and endotoxin were lower in facilities using liquid feed systems than in those feeding pigs with dry grain.[21,22]

Worker tasks have the potential to influence exposures. Moving sows significantly increased dust exposures, while moving and loading weaned piglets significantly increased both dust and endotoxin exposures.[21,23,24] Power washing with high pressure water and cleaning solutions increased worker exposures to H_2S, dust, and endotoxin.[21,24,25]

The objective of this study was to measure how pen or stall housing type, wet or dry feed type, and animal movement impact concentrations of pollutants in swine production.

Methods

Measurements were taken between June 2013 and June 2014 at the University of Minnesota's Southern Research and Outreach Center (SROC) swine facility in Waseca, MN to evaluate the effect of gestation housing, i.e. pens versus stalls, on air contaminant concentrations. NH_3, H_2S, respirable dust, respirable endotoxin, and CO_2 concentrations and temperature were measured by area sampling over 8 hours in parallel housing systems on 22 different occasions over the year. Ten of these occasions were on days on which sows were scheduled to be moved between the gestation and farrowing rooms; on the remaining 12 days, sows were not scheduled to be moved. In addition, the same 8-hour measurements were made by area sampling on 12 occasions throughout the year in a finishing building to compare air contaminant concentrations in rooms using wet and dry feed. Farm personnel performed their normal work tasks during measurement periods.

Facility

As shown in Figure 1, the SROC had two buildings housing pigs. The first held two gestation rooms and eight farrowing rooms, and the second contained four

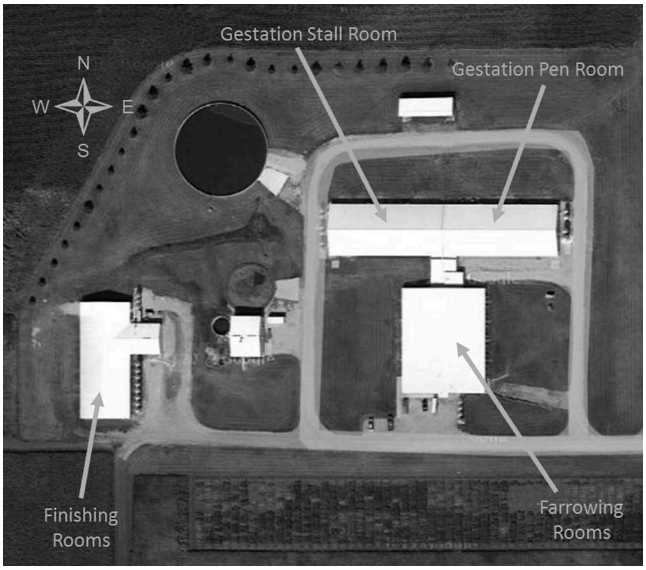

Figure 1. Aerial view of the swine facility at the University of Minnesota Southern Research and Outreach Center (original image courtesy of Google).

finishing rooms. The gestation rooms, each 18.3 m wide × 56.7 m long × 2.4 m high and holding between 250–350 pigs at any one time, differed by housing type, as shown in Figure 2. The gestation room on the west side, hereafter named the "stall room", held four rows of 60 stalls, two rows of 30 stalls, and two small pens. The pens held approximately 20 gilts each. Each stall was equipped with a drop-system feeder (Chore-Time Brock International, Milford, IN) that released feed at pre-specified times. The gestation room on the east side, hereafter named the "pen room", held six large pens with approximately 50 sows/pen, as well as one row of stalls that were used intermittently. Each pen had a centrally-located electronic sow feeder (Osborne Industries, Inc., Osborne, KS) that automatically fed sows on-demand when they walked through. Underneath each gestation room was a 2.4 m deep manure pit that was emptied twice per year. Nine 0.61 m manure pit fans and two large radial exhaust fans were available to ventilate each gestation room.

The four rooms in the finishing building were each 16.2 m long × 9.1 m wide, and each contained 16 pens, 8 per side with a walkway running through the middle. Each pen held approximately 10 animals. Pull-plug manure pits lined each room and were emptied approximately every 2 weeks. Each room had two manure pit fans and two west-facing radial exhaust fans. Animals in two rooms were fed using a liquid feeding system (Big Dutchman Inc., Holland, MI), while animals in the other two rooms were fed manually with dry feed.

Sows were moved regularly between the gestation and farrowing rooms. Workers weaned piglets every 2 weeks on Mondays and moved sows from farrowing rooms to gestation rooms. The workers then moved gestating sows into the farrowing rooms. Animals in the finishing building were moved less frequently. Piglets from the farrowing rooms were brought to the finishing building in late September and early April, where they were kept until sold, or approximately 5 months. Sales occurred in September and mid-February, meaning there were no animals in the finishing building for part of September and from mid-February to early April.

In both buildings, the amount of ventilation changed automatically in response to indoor temperature. In each gestation room, three of nine manure pit fans operated continuously even in winter unless the room temperature dropped

Figure 2. Gestation rooms at the University of Minnesota Southern Research and Outreach Center with (a) stalls and (b) pens.

below 15°C. The remaining manure pit fans turned on automatically in groups of three as temperature increased, followed by each wall fan if temperatures grew even warmer. In each gestation room, four ceiling-mounted direct-fired natural gas heaters provided heat during colder periods in response to temperature; on extremely cold days they operated continuously.

Sampling procedures

Direct-reading instruments provided measurements of NH_3, H_2S, and CO_2 concentrations and temperature in 1-minute intervals. Direct-reading gas sensors (DirectSense Electrochemical Gas Sensor, GrayWolf Sensing Solutions, Trumbull, CT) measured NH_3 and H_2S concentrations. The sensors were calibrated by the manufacturer before the start of testing, and zero levels were confirmed in the laboratory before each sampling trip. Indoor air quality meters (Q-Trak Model 8552/7575, TSI Inc, Shoreview, MN) provided CO_2 concentration and temperature measurements.

Time-integrated respirable dust and respirable endotoxin concentrations were measured from samples collected on cassette filters with Dorr Oliver cyclone respirable inlets (SKC Inc., Eighty Four, PA) using Casella Apex Lite air sampling pumps (BGI Inc., Waltham, MA). The pumps measuring respirable dust used 37 mm, 3-piece air sampling cassettes with 5.0-µm pre-weighed PVC filters (Zefon International Inc., Ocala, FL). Samples for respirable endotoxin analysis were taken using 37 mm, 3-piece air sampling cassettes with 0.4-µm polycarbonate filters (Zefon International Inc.). The air sampling pumps operated at 1.70 L/min and were calibrated before and after each sampling day using a Gilibrator-2 (Sensidyne, LP, St. Petersburg, FL). The samples were collected over a continuous 8-hour sampling period. Filters were sent to a certified industrial hygiene laboratory for analysis (EMSL Analytical Inc., Cinnaminson, NJ). Respirable dust filters were analyzed by gravimetric mass (NIOSH Method 0600). Samples taken for respirable endotoxin analysis were extracted, the extract was centrifuged, and then endotoxin in the supernatant was quantified using a kinetic chromogenic *Limulus* amebocyte lysate (LAL) assay.[26]

Two complete sets of instruments and samplers were available. Thus, simultaneous samples were always taken for 8 hours in the gestation stall and pen rooms or in adjacent wet feed and dry feed rooms in the finishing building. Sampling typically began at about 9 AM and concluded at about 5 PM. Instruments were suspended with their inlets approximately 1.5 m from the floor. In both gestation rooms, they were placed midway along the south wall, opposite from the wall with the exhaust fans. In the finishing building, instruments were hung at the end of the hallway that ran between the two rows of pens on the same wall as the exhaust fans.

Data analysis

Concentrations were plotted against time for each set of NH_3, H_2S, CO_2, and temperature measurements. Averages, standard deviations, and 95% confidence intervals were calculated from these 1-minute measurements for each 8-hour sampling period and combined into a single database with the respirable dust and endotoxin measurements. Eight-hour averages of concentrations and environmental conditions were plotted against sampling date.

Ammonia, hydrogen sulfide, and endotoxin cause similar upper respiratory tract irritant effects,[8] and workers exposed to these substances may experience additive or even synergistic effects on lung function from mixed exposures.[11] A hazard index is a way to estimate the risk posed by additive exposures to substances that produce similar health effects.[27] The hazard index for each 8-hour period was calculated from the average concentrations of NH_3 (c_{NH_3}), H_2S (c_{H_2S}), and respirable endotoxin (c_{endo}) using the equation

$$\text{Hazard index} = \frac{c_{NH_3}}{OEL_{NH_3}} + \frac{c_{H_2S}}{OEL_{H_2S}} + \frac{c_{endo}}{OEL_{endo}} \quad (1)$$

in which OEL_{NH_3}, OEL_{H_2S}, and OEL_{endo} are relevant occupational exposure limits for NH_3, H_2S, and endotoxin. We used ACGIH TLVs of 25 ppm for NH_3 and 1 ppm for H_2S, and the Dutch proposed HBROEL of 90 EU/m^3 for endotoxin for the occupational exposure limits.[8,13] These are the most conservative, i.e. lowest, limits available. A hazard index greater than 1 represents an elevated potential for adverse health effects.

For statistical analyses of differences in NH_3, H_2S, respirable dust, respirable endotoxin, and CO_2 concentrations as a function of housing and feed type, the data were transformed by taking logarithms of the concentrations to optimize the fit of the data to a normal probability distribution. For data collected in the gestation rooms, a generalized linear model (SAS, Version 9.4, Cary, NC) was used to perform a multivariate analysis of variance on the logged concentrations and temperature as a function of month, gestation room (stalls vs. pens), pig movement (sow moving day vs. non-moving day), and interactions among these factors. For data collected in the finishing barn, a generalized linear model was used to perform a multivariate analysis of variance on the logged concentrations and temperature as a function of month, feed type (wet vs. dry), and interactions between these factors. Tests of differences in means were performed according to Tukey's method. For all tests, a P-value ≤ .05 was considered significant.

Results

Analyses of measurements made in the gestation rooms indicated that no statistically significant differences ($P \leq .05$) were observed between days on which sows were moved between gestation and farrowing rooms and days without these transfers for any of the response parameters. Pigs were moved for various purposes every day, likely blurring differences among days. Data from the gestation rooms are not differentiated based on movement in subsequent analyses.

Figure 3 shows 8-hour time-weighted averages of parameters measured in the gestation stall and pen rooms as a function of date. All NH_3, H_2S, and CO_2 concentrations were below the respective OSHA PELs, NIOSH RELs, and ACGIH TLVs. Respirable dust concentrations were below the OSHA PEL and ACGIH TLV for respirable particles. Respirable endotoxin concentrations regularly exceeded the Dutch proposed HBROEL of 90 EU/m^3 from late autumn to early spring. In all cases, concentrations were significantly higher in winter than in summer ($P < .0001$) while indoor temperatures were significantly lower in winter versus summer ($P < .0001$).

As illustrated in Figure 3b, the uniquely highest 8-hour average H_2S concentration was 0.78 ppm, measured in the stall room on 14th November 2013. Figure 4 presents H_2S concentrations measured in the gestation stall room versus time on 11 test days with no preplanned movement of sows. For 10 of the days, concentrations never reached 1 ppm. On the afternoon of November 14, however, concentrations were substantially higher, reaching an instantaneous maximum of 5.19 ppm, when the gestation stalls were power washed across the room from where the sampling devices were hung, leading to the elevated H_2S concentrations. Respirable endotoxin concentrations were also uniquely high in the stall room on November 14, as shown in Figure 3d. No power washing activities were observed on other sampling days.

Figure 5 presents the hazard index in the gestation rooms as a function of date. The relationship of hazard index versus time closely matches the respirable endotoxin concentration versus time shown in Figure 3d because the respirable endotoxin is the greatest contributor to the hazard index in these measurements. The hazard index regularly exceeded 1 from late autumn to early spring. The hazard indices in the gestation rooms were significantly higher during winter than during summer ($P < .0001$).

Table 2 shows the results for statistical tests for each parameter evaluating the influence of the type of gestation housing. NH_3, respirable dust, and respirable endotoxin concentrations and the hazard index were significantly higher, on average, in the pen room than in the stall room. CO_2 concentration, on the other hand, was significantly higher in the stall room. No significant differences were observed between the gestations rooms for H_2S or temperature.

Eight-hour time-weighted averages of concentration and temperature measurements are presented in Figure 6 for finishing rooms feeding pigs with dry or wet feed. All NH_3, respirable dust, and CO_2 concentrations were below relevant OSHA PELs, NIOSH RELs, and ACGIH TLVs. Although H_2S

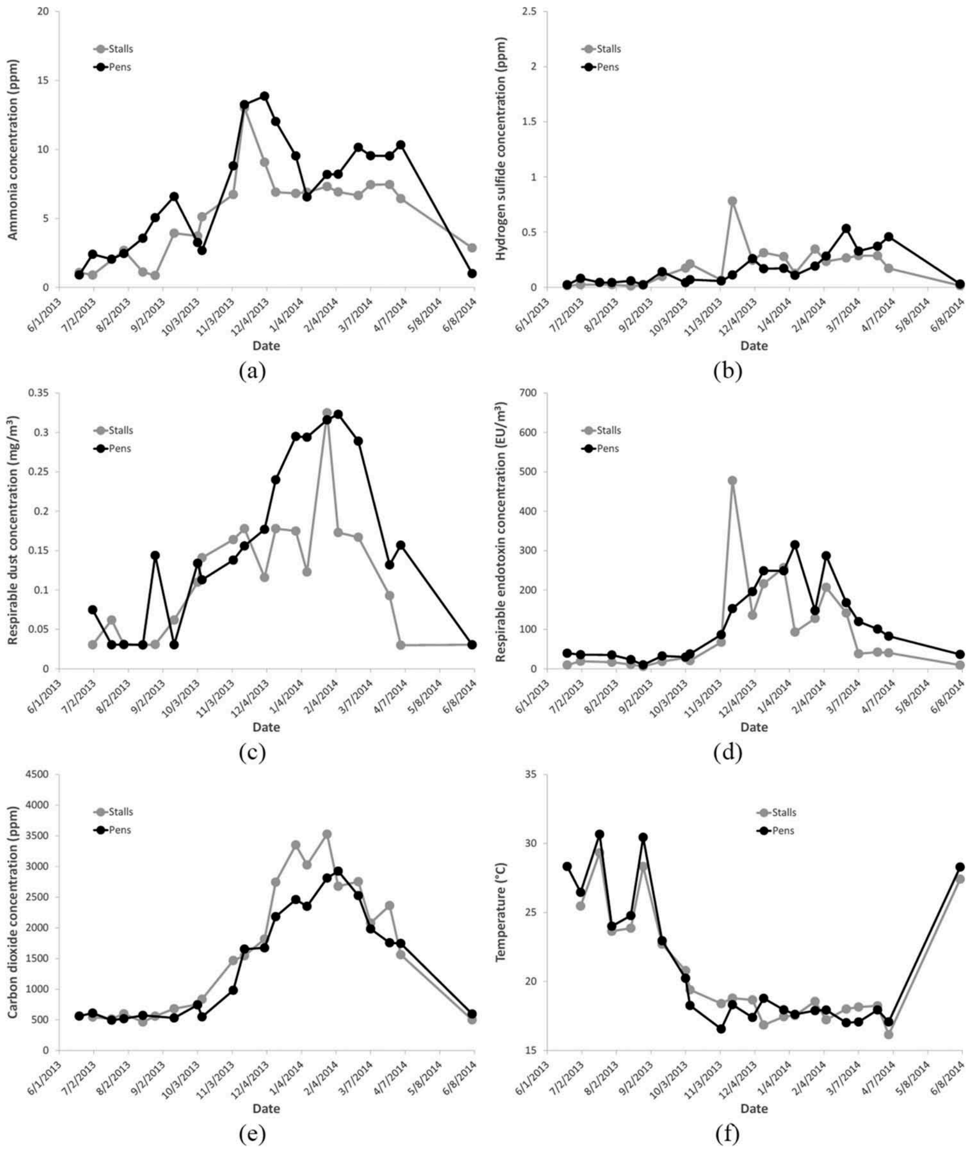

Figure 3. Measured values versus date in the gestation stall and pen rooms for (a) ammonia concentration, (b) hydrogen sulfide concentration, (c) respirable dust concentration, (d) respirable endotoxin concentration, (e) carbon dioxide concentration, and (f) temperature.

concentrations were always below the OSHA and NIOSH ceiling limits, they were higher than the 1 ppm TLV on two occasions in the dry feed room and just below the TLV on another day. Respirable endotoxin concentrations regularly exceeded the proposed HBROEL of 90 EU/m^3 during autumn in the dry feed room and in both rooms during winter. In all cases, concentrations varied significantly as a function of time, with *P*-values ranging from <.0001 to .013. Concentrations of respirable dust and endotoxin and carbon dioxide were distinctly higher during winter than during summer. Temperatures varied significantly with time ($P < .0001$), but this difference was driven more by the needs of the growing piglets than by seasonal differences.

Figure 7 shows hazard index in the finishing rooms versus date. The hazard index exceeded 1 on 9 out of 11 occasions in the dry feed room and during wintertime in the wet feed room. The hazard indices in the finishing rooms were significantly higher during winter than summer ($P = .0005$).

The results of statistical analyses to evaluate the influence of the feed type are presented in Table 2 for each parameter. No statistically significant

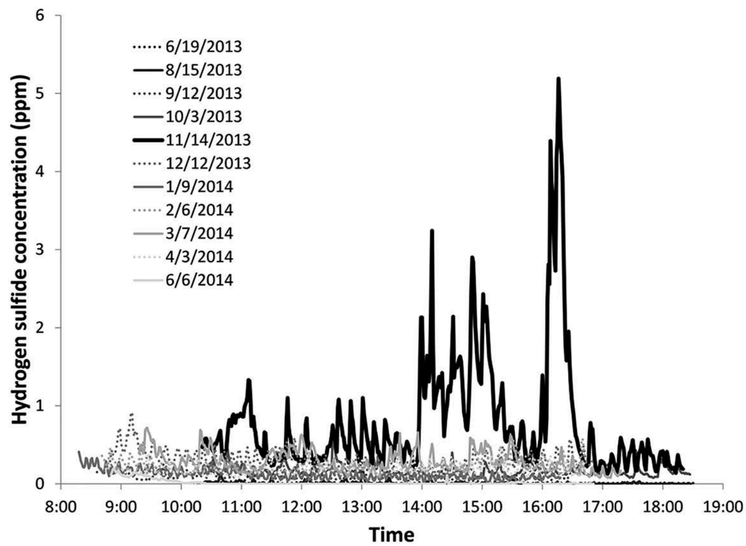

Figure 4. Hydrogen sulfide concentration in the gestation stall room versus time of day on 11 test days with no planned movement of sows between the gestation and farrowing rooms.

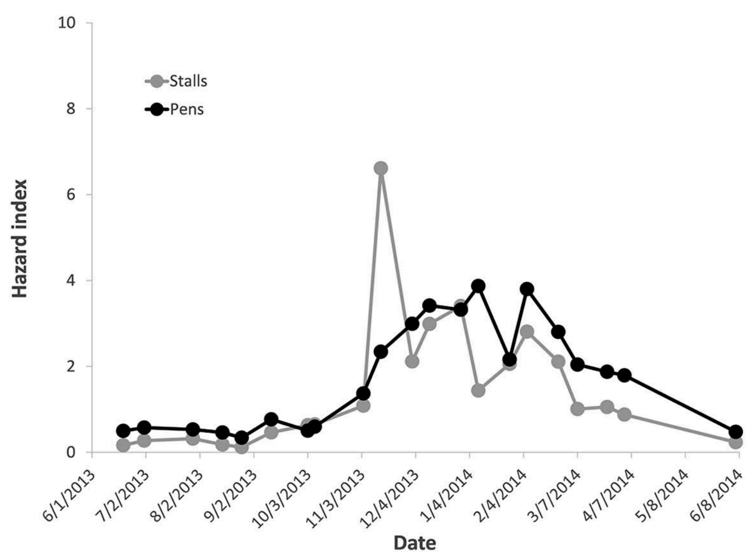

Figure 5. Hazard index – incorporating ammonia, hydrogen sulfide, and respirable endotoxin concentrations – versus date in the gestation stall and pen rooms.

differences were found for NH_3, H_2S, or respirable dust concentrations or for temperature. Respirable endotoxin concentrations were more than 5 times greater, on average, in the dry feed room than in the wet feed room, driving the hazard index to be almost 3 times greater in the dry feed room. CO_2 concentration was significantly higher in the wet feed room.

Discussion

As illustrated in Figures 3 and 6, concentrations of potentially hazardous pollutants were greater during winter than summer. The lower concentrations in summer are likely a result of high ventilation rates needed to lower temperature to maintain animal health. These results are similar to those of Reeve et al.,[17] who found significant increases in pollutant concentrations in a farrowing room when the pit fan was turned off.

In each of the gestation rooms, 3 of 9 manure pit fans ran at variable speed, faster as temperature increased, when temperatures were lower than 20° C. At around 20°C, a second set of 3 manure pit fans began operating. The hazard index was always less than 1 when the average temperature across the day was greater than 20°C. This suggests that

Table 2. Results of statistical tests for influence of gestation housing type and finishing feed type on measured parameters.

Parameter	*P* value for influence of type of gestation housing	Mean difference in parameter as a function of type of gestation housing (for significant differences only)	*P* value for influence of feed type in finishing	Mean difference in parameter as a function of feed type in finishing (for significant differences only)
Ammonia concentration	.0046	25% greater in pen room vs. stall room	.075	
Hydrogen sulfide concentration	.75		.49	
Respirable dust concentration	.025	43% greater in pen room vs. stall room	.17	
Respirable endotoxin concentration	.0001	67% greater in pen room vs. stall room	<.0001	5.4x (440%) greater in dry feed room vs. wet feed room
Carbon dioxide concentration	.015	10% greater in stall room vs. pen room	.0054	22% greater in wet feed room vs. dry feed room
Temperature	.72		.53	
Hazard index	.0004	50% greater in pen room vs. stall room	.0001	2.9x (190%) greater in dry feed room vs. wet feed room

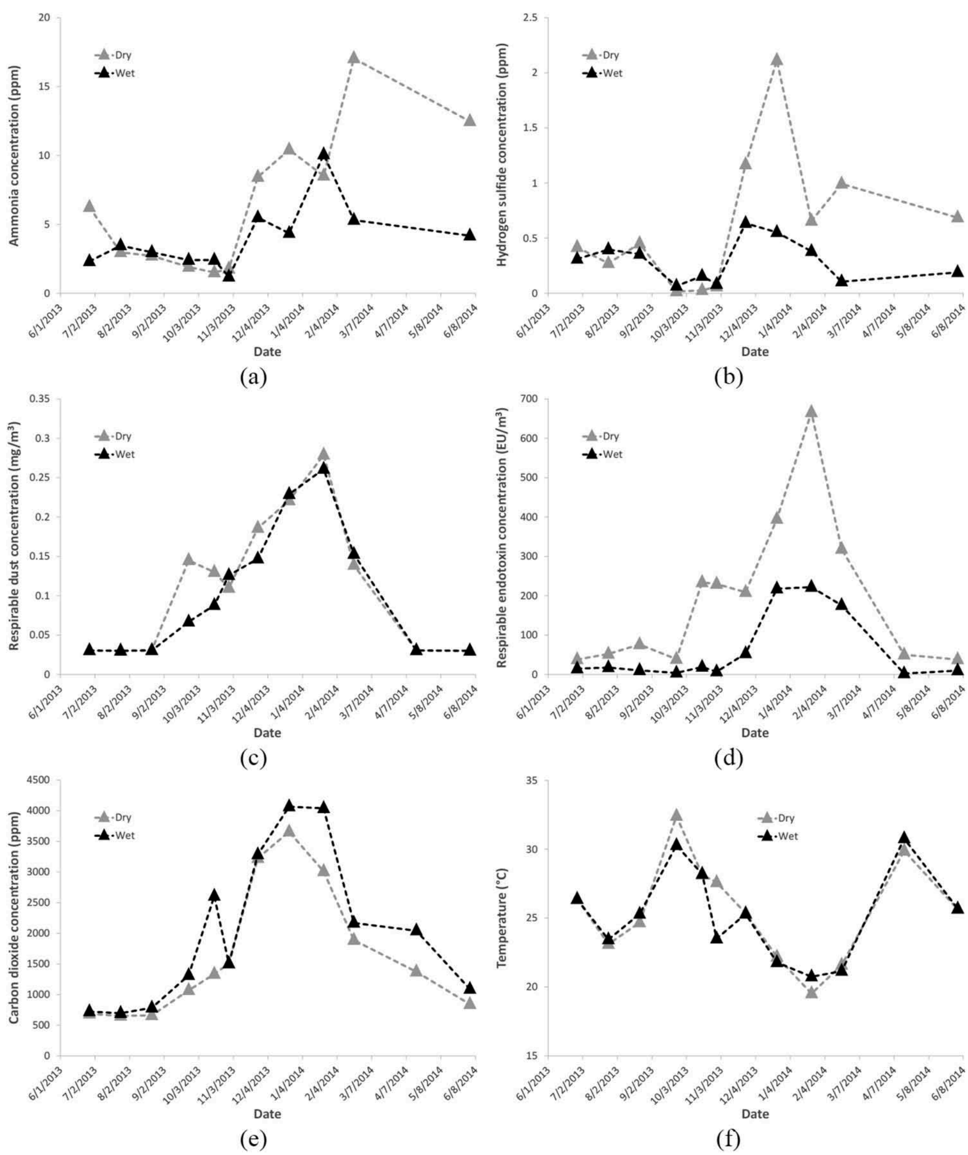

Figure 6. Measured values versus date in the finishing rooms providing dry and wet feed for (a) ammonia concentration, (b) hydrogen sulfide concentration, (c) respirable dust concentration, (d) respirable endotoxin concentration, (e) carbon dioxide concentration, and (f) temperature.

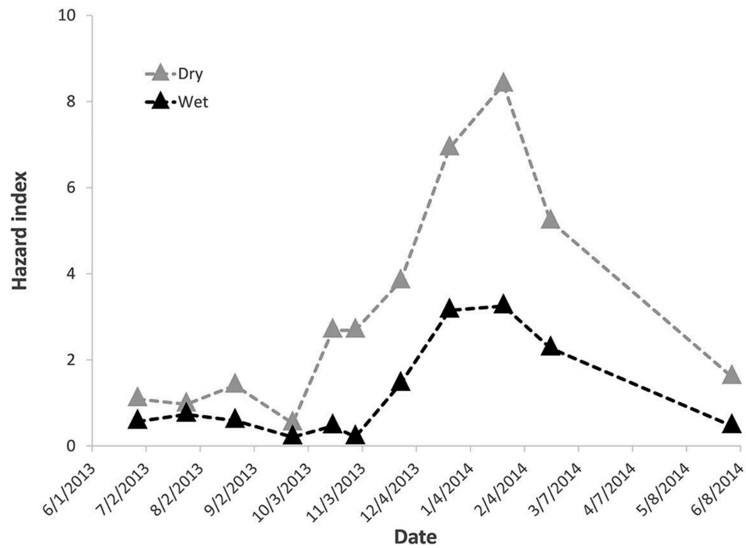

Figure 7. Hazard index – incorporating ammonia, hydrogen sulfide, and respirable endotoxin concentrations – versus date in the finishing rooms providing dry and wet feed.

operating 6 of the 9 manure pit fans in this facility would be sufficient to limit the hazard index to less than 1. Manure pit ventilation can be maximized in order to reduce pollutant concentrations. Wearing respiratory protection should be considered when the manure pit fans are at their minimal setting, especially if workers will be present for an extended period of time.

The type of gestation housing – pens or stalls – had considerably less influence on measured parameters than season. CO_2 concentration was significantly greater in the stall room, on average. This difference was likely related to the amount of natural gas burned by the direct-fired natural gas heaters rather than the production system represented by each room. NH_3, respirable dust, and respirable endotoxin concentrations were significantly higher, on average, in the pen room than in the stall room, leading the hazard index to be significantly greater in the pen room as well. Increased activity and freedom of movement in the pens likely contributed to the higher concentrations.

Endotoxin concentrations were much higher in the finishing room with dry feed than in the wet feed room, leading to a significantly greater hazard index in the dry feed room. Basinas et al.[21] and Attwood et al.[22] found similar differences between dry and wet feeding systems for both dust and endotoxin. Interestingly, feed type did not significantly affect respirable dust or H_2S levels in this study. NH_3 concentrations were higher in the dry feed room and relatively close to being significant (P = .075). CO_2 concentrations were significantly greater in the wet feed room, likely driven by the heating units.

The finding that dust concentrations did not differ significantly between the two feeding systems when endotoxin concentrations were very different was surprising. Wet feed was supplied in small amounts in 20 minute intervals, repeatedly causing the pigs to jostle for position at the feeding trough. The dry feed was supplied by hand much less frequently. Most likely, the inherently dustier dry feed did not lead to higher respirable dust concentrations due to the more frequent feeding interval of the wet feed. The higher endotoxin concentrations in the dry feed room suggest that most of the endotoxin was associated with the feed rather than with fecal matter aerosolized by movement.

Workers are exposed to respiratory hazards that may affect health additively or synergistically. Using a hazard index is one way to consider the effects of mixed exposures to air contaminants that can act additively. Our hazard index calculations used ACGIH TLVs for NH_3 and H_2S. Because there is no TLV or regulatory limit for respirable endotoxin, we used the HBROEL proposed by a Dutch expert committee, the most scientifically rigorous exposure limit available. The hazard ratios from this study were frequently ≥ 1, sometimes much greater, indicating the potential for respiratory hazards if workers are in that setting for 8 hours per day. If the inhalation hazards affect workers synergistically, as suggested by Donham et al.,[10] the hazard index will underestimate the health impacts of the exposures. However, swine workers do not typically spend all of their time in one room. The 8-hr averages measured using area samples during this study, therefore, cannot be considered representative of personal exposures.

Power washing occurred only once in the same room in which we were sampling, leading to elevated H_2S and respirable endotoxin concentrations shown in Figures 3 and 4. Notably, the sampling instruments were located across the room from where the worker was power washing, leading to the possibility that personal exposure for the worker may have been higher than measured by the area samplers. Similar measurements of elevated concentrations during power washing have been reported by Chénard et al.[25] for H_2S and by Basinas et al.[21] and O'Shaughnessy et al.[24] for endotoxin. Exposures during power washing should be studied in greater detail as workers in this facility regularly spend full days power washing farrowing rooms between litters.

Temperatures in this study averaged more than 30° C on multiple occasions in the gestation and finishing rooms, see Figures 3 and 6. Instantaneous temperatures were higher. During the summer months, swine facilities should be assessed for heat stress risks that workers may face.

A limitation of this study is the lack of a consensus standard for exposures to endotoxin. Lung function tests among workers exposed to airborne endotoxin in the swine, poultry, and grain processing/animal feed industries suggested limits of about 900, 600, and 200 EU/m^3, respectively.[4,10,12] These values are higher than the proposed Dutch HBROEL[13] of 90 EU/m^3, which was selected as the most conservative (safest) limit. The use of the Dutch limit in the hazard index means that it is greater than it would be had we chosen one of the other exposure limits for endotoxin.

Most studies of particle and endotoxin concentrations in swine production have employed total or inhalable sampling rather than respirable sampling.[6,12,14,16,19,21,23,24] Although the literature indicates that lung function is associated similarly with respirable dust and endotoxin as it is with total dust and endotoxin,[9,28] it would have been valuable to collect inhalable particle and endotoxin samples in addition to the respirable samples.

A significant strength of this project is that we were able to study two different swine gestation housing systems and two different finishing barn feeding systems in a research facility where the physical spaces were well-matched. However, because every facility has unique management practices, the ability to extrapolate findings to other swine operations is limited. For example, the facility in this study does not use an all-in-all-out system in which gestation housing is completely emptied and power-washed as sows move through the production cycle. In addition, facilities vary widely by year of construction and stage of swine production. A longitudinal study in which concentrations are measured over time, albeit less frequently, in a large number of facilities utilizing different housing and feed types would help us determine if the elevated hazard indices measured in the gestation pen room and the dry feed finishing room in this study are present industry-wide.

Numerous studies have linked exposures to air contaminants to adverse respiratory outcomes among swine workers.[1–4] Pigs are also at risk in these settings.[29,30] Respiratory diseases, by far, make up the highest proportion of nursery, grower/finisher, and wean-to-finish deaths among pigs in the U.S. swine industry.[31] A recent study evaluated porcine lung tissue *in vitro* after exposure to organic dust and found negative impacts on macrophage activation and function.[32] Reducing air contaminants in swine facilities has the potential to improve both animal and worker health.

This study was conducted in a facility in Minnesota that experiences widely varying outdoor temperatures depending on season. Findings are likely to be different were the same facility evaluated in a region that experiences different climatic conditions.

Conclusions

The main objective of this study was to determine if gestation housing and finishing feed type influence concentrations of air contaminants in swine facilities. Measurements suggested that pen housing may lead to higher levels of NH_3, respirable dust, and endotoxin, although this finding should be verified by studying a broad range of facilities. Use of a wet feed system reduced respirable endotoxin concentrations substantially. Changing ventilation rates in response to seasonal differences influenced contaminant concentrations more than housing or feed type. In winter months, hazard indices that took into account the combined effects of NH_3, H_2S, and endotoxin concentrations indicated that swine facilities may present significant respiratory hazards to workers if they must spend a significant portion of their work day in the contaminated atmosphere. In particular, increased ventilation rates and the use of respiratory protection should be considered during winter.

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