

Assessment of Swine Worker Exposures to Dust and Endotoxin during Hog Load-Out and Power Washing

PATRICK O'SHAUGHNESSY*, THOMAS PETERS, KELLEY DONHAM, CRAIG TAYLOR, RALPH ALTMAIER and KEVIN KELLY

Department of Occupational and Environmental Health, The University of Iowa College of Public Health, 105 River Street, Iowa City, IA 52242, USA

Received 7 December 2011; in final form 9 January 2012; published online 16 March 2012

Field measurements of personal and area dust and endotoxin concentrations were obtained while agricultural workers performed two work tasks that have been previously unreported: hog load-out and swine building power washing. Hog load-out involves moving hogs from their pens in finishing buildings into a truck for transport to a meat processor. High pressure power washing is conducted for sanitation purposes after a building has been emptied of hogs to remove surface and floor debris. This debris consists of feed, feces, and hog dander as dust or an encrusted form. The hog load-out process necessarily increases pig activity which is known to increase airborne dust concentrations. An unintended consequence of power washing is that the material covering surfaces is forcibly ejected into the atmosphere, creating the potential for a highly concentrated aerosol exposure to workers. The load-out process resulted in a median personal inhalable mass concentration of 7.14 mg m^{-3} and median endotoxin concentration of $12\ 150 \text{ endotoxin units (EU) m}^{-3}$. When converted to an 8-h time-weighted average for a 'total' sampler, one of the 19 samples exceeded a regulatory limit of 15 mg m^{-3} . An impinger was used to sample power washing endotoxin concentrations, which resulted in a median personal concentration of $40\ 350 \text{ EU m}^{-3}$. These concentrations were among the highest found in the literature for any occupation. With the lack of engineering controls present to reduce airborne contaminant concentrations in swine buildings, either respirator use or a reduction in exposure time is recommended while performing these tasks.

Keywords: endotoxin; impinger; finishing building; power washing; swine

INTRODUCTION

Workers associated with the pork industry in the USA can be involved in a variety of work tasks. These tasks include those needed to care for young females to be impregnated (gilts), nursing piglets, and finishing pigs for market. Likewise, the various aspects of pork production are housed in specialized buildings, or rooms within large buildings, for specific processes such as farrowing (birthing) piglets, isolating new pigs, or raising pigs to be slaughtered for meat. Given a variety of tasks and structures, as well as a number of sources of airborne contaminants, workers in this industry are exposed to a wide

range of respiratory irritants in the form of gases, dusts, and chemical compounds. These exposures have resulted in an elevated risk of acquiring a number of respiratory ailments compared to those in other industries (Choudat *et al.*, 1994; Schwartz *et al.*, 1992; Larsson *et al.*, 1994; Pedersen *et al.*, 1996; Monso *et al.*, 2004).

Previous research by members of this study team has demonstrated a synergistic relationship of swine confinement dust and ammonia that caused a decline in cross-shift lung function at lower levels than may occur in environments with only one of those contaminants present (Donham *et al.*, 1995; Reynolds *et al.*, 1996). These studies resulted in a recommended time-weighted average (TWA) dust exposure level of 2.5 mg m^{-3} in swine and poultry houses as measured by a 37-mm closed-face cassette (CFC).

*Author to whom correspondence should be addressed.
Tel: 319-335-4202; fax: 319-335-4225;
e-mail: patrick-oshaughnessy@uiowa.edu

Furthermore, a subsequent side-by-side comparison of the CFC and IOM inhalable sampler in swine buildings resulted in a CFC/IOM ratio of 0.56 (Reynolds *et al.*, 2009). Therefore, a recommended exposure level (REL) based on an IOM sampler reading would be 4.5 mg m^{-3} .

In a previous study, we identified tasks involved with farrowing and gestation that are a significant determinant of inhalable dust exposures (O'Shaughnessy *et al.*, 2010). We found that some tasks increased pig activity, such as when weaning piglets, which re-suspended settled dust and increased aerosol concentrations. Levels also varied between seasons because of changes in ventilation rates, where lower rates are applied in the winter to minimize heat loss resulting in higher concentrations. For example, geometric mean (GM) personal exposures varied between 0.83 mg m^{-3} in the summer to 3.76 mg m^{-3} in the winter. Therefore, the REL will typically not be exceeded in summer months but can be during winter periods in the Midwestern USA when temperatures do not exceed the minimum recommended indoor level of 14°C (Mount, 1975) for many months. For example, during the study of O'Shaughnessy *et al.* (2010), 42% of the personal samples taken in the winter exceeded 4.5 mg m^{-3} whereas no summer samples were greater than that amount. They also measured personal endotoxin concentrations that resulted in GM concentrations that varied between 550 and 713 endotoxin units (EU) m^{-3} during the summer to winter months, respectively. The engineering recommendations for ventilation of swine buildings are based on removal of the moisture and heat that pigs produce and not aerosols and gases that may be a worker health hazard. Therefore, our research, as well as that of others (Pickrell *et al.*, 1993; Maghirang *et al.*, 1997; Pedersen *et al.*, 1996), demonstrates that swine buildings are uncontrolled work environments from the standpoint of minimizing airborne hazards that affect workers' health. This condition points to the need to further assess swine worker exposures by focusing on tasks that will most likely produce high contaminant concentrations.

The purpose of this study was to expand our research conducted in gestation/farrowing buildings by assessing airborne dust and endotoxin concentrations produced in finishing buildings. Of the many tasks performed by swine workers in finishing buildings, two were selected for further study because of their potential to produce high dust concentrations: hog load-out and power washing. Hog load-out is performed whenever a number of hogs need to be moved from a building into a truck for transport to a meat processor. This task accentuates pig activity

which is known to elevate dust levels (Gustafsson, 1999; O'Shaughnessy *et al.*, 2010).

Power washing with high-pressure water sprayers is performed after pigs are removed from a building or room and prior to when the next group of pigs enters. Given the contact of highly accelerated water droplets onto areas to be cleaned, this operation necessarily dislodges and aerosolizes material settled onto flooring, gates, and other surfaces. Exposure to particulates dislodged during this process has been shown to cause a significant increase in bronchial responsiveness to a methacholine challenge in healthy volunteers (Larsson *et al.*, 2002). Furthermore, water spraying has the potential to significantly raise the relative humidity of a room while cleaning which, anecdotally, increases worker discomfort and difficulty using respiratory protection. We are unaware of any scientific literature that addresses dust and endotoxin conditions while performing these tasks.

METHODS

Study sites and population

Five swine finishing operations located in central Iowa and owned by the same company were visited over a 2-year period. These facilities are typical of those used in modern swine production in the central USA. The buildings were 19-m wide by 75-m long with a central aisle that divided pen areas on either side of the building. Each site contained two buildings connected by an enclosed corridor. The buildings contained open-slat flooring. End wall fans ventilated the buildings during the winter and moveable side curtains were used for ventilation in warm weather. The capacity of each building was 1248 hogs.

For the hog load-out task, the study population was selected from workers engaged in the task for at least 150 min during any 1 work day. The hog load-out task involves moving market-weight pigs ($\sim 110 \text{ kg}$) out of their pens and into a truck to be transported to a meat processing plant. During the process, each building on a site would be emptied of ~ 200 hogs requiring ~ 160 min to complete. After completing the task in the first building, the workers typically moved to the second building to restart the process. Three workers would sort the pigs to be moved and push them with plastic panels into the central aisle where another three workers pushed them toward the exit door and onto a ramp leading into the truck. Typically three to four workers were sampled during each visit for a total of 19 personal samples. Each worker was actively engaged in the hog load-out task during the sampling episode.

During each visit, an area sampling station was also established near the center of the building.

For the power-washing task, workers were selected from eight sites in central Iowa. Three sites were finishing buildings similar those described above and the other five were gestation buildings as described by O'Shaughnessy *et al.* (2010). Depending on the number of workers at each site involved with power washing, one or two personal samples and one to three area samples were taken at each site for a total of 13 personal and 17 area samples. During five sampling episodes, additional area samples were taken prior to power washing as an indication of background concentrations. During the power-washing task, a worker would start at one end of room and move to the other end while spraying in the direction of movement. All surfaces within the room including walls, pen railings, floor grates, and feed dispensers were washed thoroughly. The hot water power washers were operated with 3500 psi water pressure and equipped with a spinning nozzle.

Sampling procedures—load-out operation

The hog load-out process typically occurred over a 2- to 3-h period. During that time, workers wore an inhalable dust sampler (IOM; SKC Inc., Eighty Four, PA, USA) attached to their right shirt lapel. This sampler was designed to conform to the American Conference of Governmental Industrial Hygienists/International Organization for Standardization/European Committee for Standardization inhalable convention, which describes an efficiency curve that is nearly 100% for particles <5 μm and descending to 50% efficiency at 100 μm (ACGIH, 2010). A flexible sample line attached a pressure-compensating sampling pump (Model 224-PCXR4; SKC Inc.) to the sampler set to deliver a flow rate of 2 l min^{-1} . A Gilibrator[®] (Sensidyne, Clearwater, FL, USA) was used to pre- and post-calibrate pump flow rates. The IOMs were equipped with 25-mm polyvinyl chloride filters with a 5- μm pore size. Filters were weighed using a calibrated Mettler MT5 six-place balance (Mettler-Toledo, Inc., Columbus, OH, USA) placed in a dedicated climate-controlled room. Filter handling and analysis methods given in National Institute for Occupational Safety and Health method 0500 were followed. This included offsetting mass collected on a filter by any change measured in a field blank filter and maintaining room conditions near 20°C and 50% RH. After the post-weighing process, the entire IOM cassette with filter was transferred to a sterile 50-ml centrifuge tube and stored in a 4°C refrigerator for up to 6 months prior to the endotoxin analysis.

Area samples were taken by suspending sampling instruments in a mesh basket just above head height in the area occupied by workers during a load-out and moved with the workers to the adjacent building when performing the second load-out of the day. Sampling instruments included an IOM with associated pump and a direct-reading instrument (Q-trak; TSI Inc., Shoreview, MN, USA) used to record temperature, relative humidity, and carbon dioxide every minute. Area samples also contained additional equipment including an optical particle counter (Model 1.108; Grimm Technologies, Inc., Douglasville, GA, USA) capable of distinguishing particles between 0.3 and 20 μm and an aerosol photometer (pDR-1200 DataRam; Thermo Scientific, Waltham, MA, USA) that recorded aerosol mass concentrations every 15 s. The aerosol photometers were operated in active mode which involved the use of vacuum pump to pull air through the instrument and a downstream filter cassette. The mass concentration obtained from the filter was then used to calculate a correction factor to all readings so that their overall average concentration was equivalent to the filter concentration.

Sampling procedures—power washing

We were not aware of any other studies in which airborne samples were taken during a power washing process in a swine building. Therefore, there is no precedent for the proper sampling procedure. Given an expectation that the power washed room would reach a relative humidity of 100% with both droplets and dust particles present, we concluded that an impinger would be a more robust sampling device than an IOM in such an environment. However, an impinger does not provide a measure of mass concentration of aerosol. Therefore, only endotoxin concentrations were obtained when using this instrument. Impingers sample particles by impaction and therefore preferentially collect larger particles. Spanne *et al.* (1999) demonstrated that the impinger used in this study has a 50% cut diameter near 1.3 μm at 1 l min^{-1} , which would be even lower at the higher flow rate used in this study.

A standard 25-ml midget impinger (SKC Inc.) with a secondary water trap prior to the pump was used to perform personal and area sampling during power washing. Air was pulled through the impinger with the use of a pressure-compensating pump (Model 224-PCXR4; SKC Inc.) at a flow rate of 2 l min^{-1} . Before each sample period, 10 ml of pyrogen-free water was added to the impinger. After sampling, the liquid sample was transferred to a sterile 50-ml centrifuge tube and stored for up to 6 months in a 4°C refrigerator prior to the endotoxin

analysis. Personal samplers were attached to hang from the worker's right shoulder facing forward.

Area samplers were placed in hanging baskets at the front end of a room immediately after that area of the room had been sprayed. Consequently, area sampling started after the initiation of the power washing process in a room but this plan avoided having the samplers located in an area yet to be sprayed that might result in damage to the sampling devices. The optical particle counter was not used because of concern that it may be damaged when used in this high humidity environment. Therefore, the particle size distribution was measured with an 8-stage cascade impactor (Marple Series 290; Thermo Fisher Scientific) with Mylar substrates.

Endotoxin analysis

Endotoxin concentrations were determined using a kinetic *Limulus* amoebocyte lysate (LAL) assay (Lonza, Walkersville, MD, USA) applied to the aerosol samples collected with the inhalable samplers and the impinger samples taken during power washing as described by Vojta *et al.* (2002). In brief, dust from filter samples was extracted in sterile, pyrogen-free water with 0.05% Tween-20 by shaking for 1 h and then centrifuged for 20 min at 600 G. The supernatant was then analyzed using the kinetic chromogenic LAL assay. Field blanks, one for each sample period, were also analyzed in the same way. Liquid samples taken from impingers were vortexed for 5 min prior to direct analysis with the LAL assay. Any dilutions necessary were made with pyrogen-free water without Tween. A 13-point calibration curve ranging from 0.05 to 100 EU/ml modeled with a four-parameter equation with an $R^2 = 0.999$ was

developed. Quality assurance spiking assays were performed to assess matrix interference or enhancement, which did not result in either effect, so no corrections were made. The limit of detection of this assay when analyzing these samples was 0.024 EU/ml of eluted sample.

Data analysis

Gravimetric analysis of the inhalable sampler filters was used to compute an inhalable dust exposure level, expressed as mg m^{-3} , for each study subject over the sample time period. An 8-h TWA inhalable concentration was also determined to normalize for differences in the actual period of work. Results from the endotoxin analysis were expressed as EU m^{-3} . The software, Excel (Microsoft Corp., Seattle, WA, USA), was used to perform descriptive statistics and graphical analysis was used to describe and present the central tendency and variability of the measured exposure levels. Linear regression analysis was also performed to demonstrate relationships between variables. A P value <0.05 was considered statistically significant.

RESULTS

Hog load-out task

A representative plot of dust concentrations recorded by an aerosol photometer placed in an area sampling location prior and during a load-out process is shown in Fig. 1. During this sample period, the median concentration while loading hogs was 3.05 mg m^{-3} with a range of $0.09\text{--}14.53 \text{ mg m}^{-3}$ compared to a median of 1.12 mg m^{-3} with a range of $0.79\text{--}2.31 \text{ mg m}^{-3}$ prior to the loading activity.

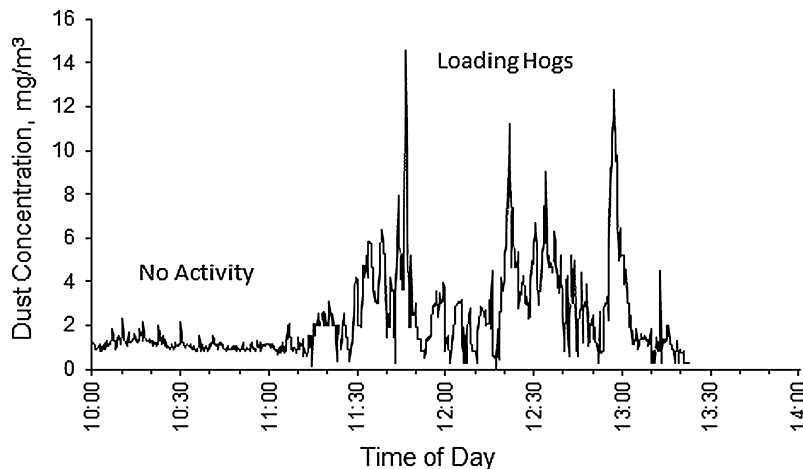


Fig. 1. Real-time measurements of area dust concentrations before and during a hog load-out operation.

Environmental conditions inside three finishing buildings measured during the hog load-out operation and over three seasons are given in Table 1. Carbon dioxide (CO₂) concentrations remained near 2000 ppm in each season. In general, temperatures were lower in the winter than in the other seasons and relative humidity levels were higher. These values are not necessarily indicative of indoor conditions when not loading hogs as a door to the building was open during much of this operation while hogs were moved onto the receiving truck.

Histograms of the size distribution of particles measured by the particle counter placed near the area sampler are shown in Fig. 2. Particle diameter measured by an optical particle counter is roughly equivalent to the actual diameter of the particle rather than its aerodynamic diameter. The distributions shown in Fig. 2 are representative of those measured in the finishing barns. The three measurements using the optical particle counter resulted in an average count median diameter of 0.6 µm, average mass median diameter of 5.6 µm, and average geometric standard deviation (SD) of 2.2. As shown in Fig. 2, the particle size based on mass diminishes dramatically for particles <2 µm.

Personal dust concentrations exhibited a lognormal distribution; therefore, the GM and geometric

Table 1. Summary statistics for area environmental conditions measured during the hog load-out operation by season.

	CO ₂ (ppm)	Temperature (°C)	Relative humidity (%)
Spring	1890	20	57
Fall	2304	14	82
Winter	1870	8	89

SD were computed to express the central tendency and spread of these concentrations. As provided in Table 2, personal dust concentrations varied considerably between 2 and 31 mg m⁻³. Personal endotoxin concentrations also exhibited a wide range of values between 3497–84 357 EU m⁻³, with a GM of 12 659 mg m⁻³ and geometric SD of 2.67 (Table 3). All field blanks for endotoxin resulted in concentrations that were less than the assay limit of detection. As shown in Fig. 3, a linear relationship between dust and endotoxin concentrations demonstrated that the highest dust concentrations coincide with the highest endotoxin levels, but below 15 mg m⁻³, there is no association between the two measures as indicated by the low *R*² value (0.0359) and an insignificant slope (*P* = 0.48).

Area dust concentrations ranged between 1.67 and 6.72 mg m⁻³, with a GM of 3.18 mg m⁻³ and geometric SD of 1.88. The range of area concentrations represents a conservative estimate of conditions in the buildings as they were calculated with the inclusion of some 'down time' periods between load-outs. An assessment of concentrations recorded by the photometers only during the load-out processes revealed a range of 2.90–11.57 mg m⁻³. A strong linear relationship (*R*² = 0.96) between area measurements and the average of all personal dust measurements (that likewise included down time periods) measured on a site is shown in Fig. 4. When the regression was performed without an intercept term, a slope of 3.3 was developed which provides the general relationship between personal and area samples. Area endotoxin values ranged from 2771 to 19 281 EU m⁻³, with a GM of 7997 EU m⁻³ and geometric SD of 2.22. These values were approximately one-

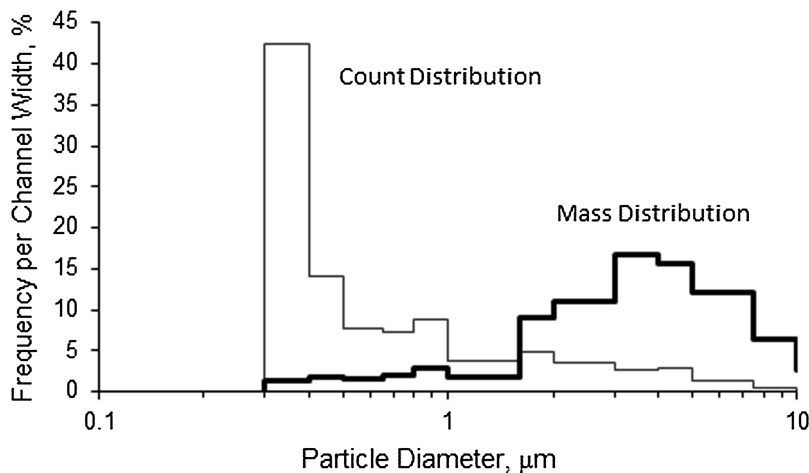


Fig. 2. Representative count and mass distribution of particles sampled in a finishing barn.

Table 2. Summary statistics for personal and area dust concentrations measured during the hog load-out operation.

	Sample size	GM (mg m^{-3})	Geometric SD	Range (mg m^{-3})
Personal sample	19	7.14	2.26	2.01–31.06
Personal 8-h TWA	19	3.17	2.57	0.47–28.57
Area sample	5	3.18	1.88	1.67–6.72

Table 3. Summary statistics for personal and area endotoxin concentrations measured during the hog load-out operation.

	Sample size	GM (EU m^{-3})	Geometric SD	Range (EU m^{-3})
Personal sample	19	12 150	2.69	3497–84 357
Personal 8-h TWA	19	5966	3.12	1195–78 206
Area sample	5	7996	2.22	2771–19 280

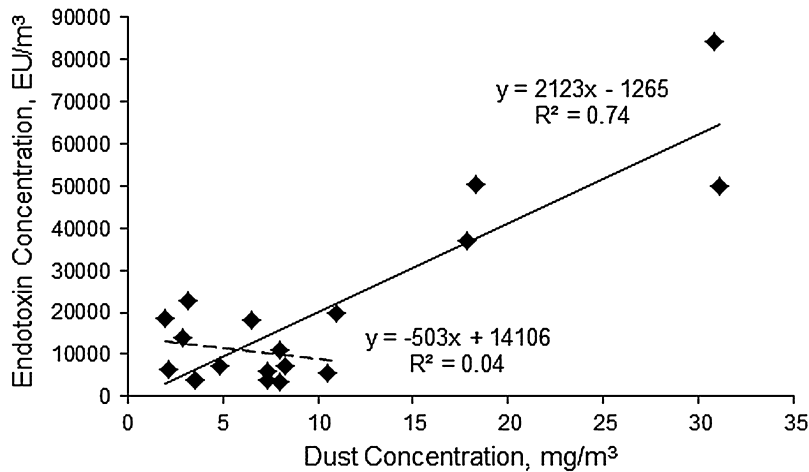


Fig. 3. Personal dust and endotoxin concentrations showing a linear equation and R^2 value for the entire data set (solid line) and for dust levels $< 15 \text{ mg m}^{-3}$ (dashed line).

half of those obtained from the personal samples (Table 3).

Power washing task

Endotoxin concentrations measured during power washing sampling episodes are shown in Table 4. As when measuring the personal endotoxin levels from filter samples, there was a very wide range between the lowest and highest values obtained (5401–180 864 EU m^{-3}). The GM of prewash levels (9378 EU m^{-3}) was $\sim 25\%$ of that obtained for personal endotoxin samples and significantly less than the area samples ($P = 0.026$). Both personal and area samples of endotoxin during power washing greatly exceeded those measured during the load-out task. Here the area endotoxin samples, with a range of 25 545–340 846 EU m^{-3} , were greater than those obtained from the personal samples.

The particle size distribution measured with the cascade impactor during a power washing sampling

episode resulted in a mass median aerodynamic diameter of $12.8 \mu\text{m}$ with a geometric SD of 2.5. With the use of equations to define the respirable and inhalable fraction of an aerosol (ACGIH, 2010), the respirable fraction of this aerosol was determined to be 14% and an inhalable fraction of 73%.

DISCUSSION

During this study, personal dust concentrations measured during the hog load-out task resulted in a GM of 7.14 mg m^{-3} and area measurements resulted in a GM of 3.18 mg m^{-3} . By comparison, Donham *et al.* (1985) compiled results from several comparable studies and reported typical levels of total airborne dust measured with 37-mm cassettes in swine confinement operations range between 2 and 6 mg m^{-3} . Reynolds *et al.* (2009) made 10 consecutive area measurements in two finishing barns with the use of an IOM sampler that resulted in an overall

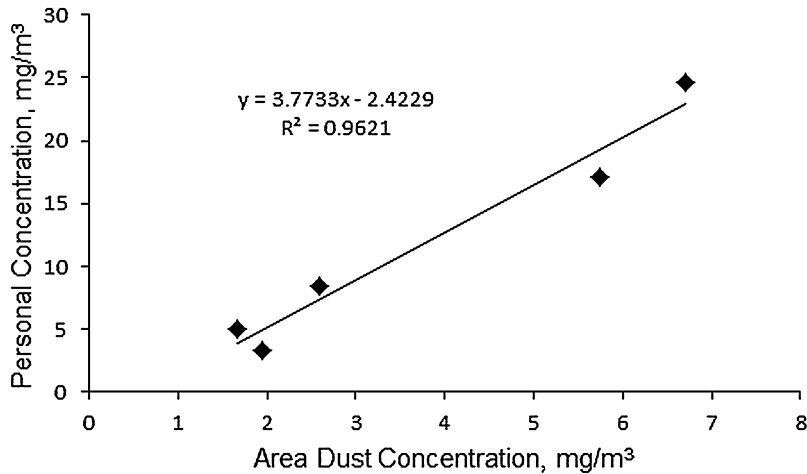


Fig. 4. Linear relationship between area dust concentrations and the average of personal dust concentrations measured at the same site.

Table 4. Summary statistics for personal and area endotoxin concentrations measured during the power washing operation.

	Sample size	GM (EU m ⁻³)	Geometric SD	Range (EU m ⁻³)
Prewash sample	5	9378	4.08	1913–32 422
Personal sample	13	40 353	2.26	5401–180 864
Area sample	17	88 112	1.73	25 545–340 846

mean dust level of 3.0 mg m⁻³. Robertson (1993) reported a mean area dust level of 2.8 mg m⁻³ measured in seventy finishing barns with 37-mm cassettes. The highest arithmetic mean dust levels in swine buildings found in the literature were reported by Heber and Stroik (1988) with mean levels of ‘total’ dust of 8.8 and 6.9 mg m⁻³, respectively, for naturally and mechanically ventilated finishing barns. Fewer personal swine worker dust measurements are provided in the literature. Donham *et al.* (1989) report an arithmetic average of 6.8 mg m⁻³ among 57 workers in Sweden, and O’Shaughnessy *et al.* (2010) reported a range of personal concentrations between 0.83 and 3.76 mg m⁻³ between summer and winter measurements on 12 gestation barn workers, respectively.

As highlighted by this review of dust concentrations found in the literature, a comparison between studies is complicated by differences in: (1) the sampler used, (2) the measure of central tendency—geometric or arithmetic mean—reported, and (3) whether personal or area measurements were taken. Many studies before 2000 were conducted with filters housed in a ‘total’ sampler consisting of a three-piece cassette, while more recent studies, including this one, used the ‘inhalable’ IOM sampler. For example, using the cassette/IOM ratio of 0.56

reported by Reynolds *et al.* (2009), the typical range reported by Donham *et al.* (1985) would be 3.6–10.7 mg m⁻³ if sampled with an IOM inhalable sampler as occurred in this study. Likewise, the high total dust value of 8.8 mg m⁻³ reported by Heber and Stroik (1988) is equivalent to an IOM value of 15.7 mg m⁻³.

Comparison between studies is also complicated by differences in sample time and whether the exposure concentrations were normalized to an 8-h work shift. In relation to the proposed inhalable dust REL of 4.5 mg m⁻³, 5 of the 19 personal samples converted to an 8-h TWA exceeded this value (26%). Furthermore, measurements made by the Occupational Safety and Health Administration (OSHA) for enforcement of dust standards are based on the use of the 37-mm cassette. The range of personal 8-h TWA dust values reported in Table 2 would be 0.26–15.99 mg m⁻³ if sampled with a cassette, resulting in the highest of the 17 personal samples exceeding the OSHA permissible exposure limit (PEL) for ‘particulates not otherwise classified’ of 15 mg m⁻³ (OSHA, 2011). One method for minimizing exposure levels below these limits is to minimize the task time. For example, if we desire to protect workers in conditions that represent the 90th percentile of concentrations measured in this study

(20.3 mg m⁻³), then the formula, $(C \times t)/8 = 4.5$, could be rearranged to solve for the exposure time, t , associated with an 8-h TWA of 4.5 mg m⁻³. In this case, for $C = 20.3$ mg m⁻³, t would equal 1.8 h or 106 min. The same calculation applied to the OSHA PEL would be 5.9 h or 350 min.

Endotoxin concentrations measured during this study resulted in the highest reported in the literature for indoor environments associated with agricultural. In its review of scientific literature on respiratory health hazards in agriculture, the ATS (1998) reported four studies in which endotoxin concentrations were measured in swine buildings that ranged between 400 and 2800 EU m⁻³ (Clark *et al.*, 1983; Atwood *et al.*, 1987; Donham *et al.*, 1989; Preller *et al.*, 1995). The highest endotoxin values provided in that review were those found by Thelin *et al.* (1984) in chicken buildings that ranged from 1,300 to 10 900 EU m⁻³. High values of endotoxin have been also been reported in more recent publications. Thorne *et al.* (1997) report a range of 2040–24 100 EU m⁻³ with a median of 8290 EU m⁻³ for endotoxin in six swine barns in eastern Iowa. In a recent study by Letourneau *et al.* (2010), the effect of different swine production systems on bioaerosol production was compared during which they measured a mean concentration of 26 700 EU m⁻³ for buildings with slatted floors, a level that exceeds the GM measured during the hog load-out process (12,150 EU m⁻³) in this study. Likewise, Dungan (2011) measured an average concentration of 49 066 EU m⁻³ in a swine finishing barn that is in the range of personal measurements made in this study during the load-out operation. The highest endotoxin concentration found in the literature was 88 500 EU m⁻³ reported by Olenchok *et al.* (1987) when sampling in the top of a silo during an unloading operation, but this value was greatly exceeded by the maximum measurement obtained here of 340 800 EU m⁻³.

As with dust concentrations, endotoxin values reported in the literature can also be difficult to compare if the sampling device differs between studies. In this study, two different devices, an IOM sampler and a standard impinger, were used to obtain endotoxin concentrations. These two devices have different inlets and, therefore, different aerosol aspiration efficiencies. However, neither includes a mechanism, such as a cyclone, to purposely exclude large particles. This is important because the size distribution measured for both the load-out and power washing tasks indicate that a majority of the particles suspended by these activities are not respirable, defined as those

particles collected with a sampler with a 50% cut diameter <4 µm.

There are no standards for endotoxin exposure promoted by an agency in the USA. A cohort study of 54 swine farms in Sweden revealed an exposure to endotoxin concentrations greater than 0.1 µg m⁻³ (1000 EU m⁻³) is a risk factor for obstructive lung disease (Donham *et al.*, 1989). A more conservative REL for endotoxin was suggested by an expert committee associated with the Health Council of the Netherlands (HCN, 2010). That committee proposed an 8-h TWA of 90 EU m⁻³ based on their conclusion that this value represented a no-observed-effect level (NOEL) for a worker inhaling that level of endotoxin over a 40-year work life. The committee principally relied on a study by Castellan *et al.* (1987) as the basis for the REL, which linked exposure to endotoxin on cotton dust with the change in forced expiratory volume at one second (FEV₁) over a work shift. This REL can also be viewed relative to illnesses and symptoms known to be caused by endotoxin exposure and the endotoxin concentrations that can produce those effects: organic dust toxic syndrome (ODTS) is elicited at levels of 10 000–20 000 EU m⁻³; acute bronchitis can occur at levels of 1000–2000 EU m⁻³; and mucous membrane irritation occurs at levels of 200–500 EU m⁻³ (Olenchok 1994). The high endotoxin exposure levels found in this study, therefore, often exceeded those that can produce ODTS. Given the lack of engineering controls for minimizing airborne contaminants in these buildings and that no level of endotoxin measured was below 1000 EU m⁻³, donning a respirator is the only effective means of reducing these exposures to the REL level.

CONCLUSIONS

Inhalable dust and endotoxin concentrations were measured in modern swine buildings when workers were involved in the tasks of hog load-out and power washing. Both tasks involved processes that aerosolized particles either by enhanced swine activity during load-out or by ejecting particles off surfaces during power washing. In both cases, high concentrations of dust and endotoxin were produced. Although the median concentration of personal dust exposures fell below a regulatory standard, measurements during the hog load-out task demonstrated that personal dust levels can exceed the standard. Furthermore, one-quarter of the personal dust measurements exceeded an REL. Although an occupational standard for endotoxin does not exist, the levels obtained during both tasks, but especially

when power washing, suggest that workers performing those tasks are at risk of developing ODS.

FUNDING

National Institute for Occupational Safety and Health (U50 OH007548 to the Great Plains Center for Agricultural Health); the National Institute of Environmental Health Sciences (P30 ES05605).

Acknowledgements—The authors are grateful for the assistance of Dr Nervana Metwali for performing the endotoxin analysis of all samples associated with this study.

REFERENCES

- ACGIH. (2010) Threshold limit values and biological exposure indices. Cincinnati, OH: ACGIH.
- ATS. (1998) Respiratory health hazards in agriculture. *Am J Crit Care Med*; 158: S1–76.
- Atwood P, Brouwer R, Ruigewaard P *et al.* (1987) A study of the relationship between airborne contaminants and environmental factors in Dutch swine confinement buildings. *Am Ind Hyg Assoc J*; 48: 745–51.
- Castellan RM, Olenchock SA, Kinsley KB *et al.* (1987) Inhaled endotoxin and decreased spirometric values. An exposure-response relation for cotton dust. *N Engl J Med*; 317: 605–10.
- Choudat D, Goehen M, Korobaef M *et al.* (1994) Respiratory symptoms and bronchial reactivity among pig and dairy farmers. *Scand J Work Environ Health*; 20: 48–54.
- Clark S, Rylander R, Larsson L. (1983) Airborne bacteria, endotoxin and fungi in dust in poultry and swine confinement buildings. *Am Ind Hyg Assoc J*; 44: 537–41.
- Donham KJ, Reynolds SJ, Whitten P *et al.* (1995) Respiratory dysfunction in swine production facility workers: dose-response relationships of environmental exposures and pulmonary function. *Am J Ind Med*; 27: 405–18.
- Donham K, Scallon L, Pependorf W *et al.* (1985) Characterization of dusts collected from swine confinement buildings. *Am Ind Hyg Assoc J*; 46: 658–61.
- Donham K, Haglund P, Peterson Y *et al.* (1989) Environmental and health studies of farm workers in Swedish swine confinement buildings. *Br J Ind Med*; 46: 31–7.
- Dungan RS. (2011) Airborne endotoxin form indoor and outdoor environments: effect of sample dilution on the kinetic Limulus amoebocyte lysate (LAL) assay. *J Occup Environ Hyg*; 8: 147–53.
- Gustafsson G. (1999) Factors affecting the release and concentration of dust in pig houses. *J Agric Eng Res*; 74: 379–90.
- HCN. (2010) Endotoxins: health-based recommended occupational exposure limit. Publication no. 2010/04OSH. The Hague, The Netherlands: Health Council of the Netherlands.
- Heber AJ, Stroik M. (1988) Influence of environmental factors on dust characteristics in swine finishing houses. *Livestock Environment III, Third International Symposium, Toronto, Ontario, April 25–27*. pp. 291–98.
- Larsson KA, Eklund AG, Hansson LO *et al.* (1994) Swine dust causes intense airways inflammation in healthy subjects. *Am J Respir Crit Care Med*; 150: 973–7.
- Larsson B-M, Larsson K, Malmberg P *et al.* (2002) Airways inflammation after exposure in a swine confinement building during cleaning procedure. *Am J Ind Med*; 41: 250–58.
- Letourneau V, Nehme B, Meriaux A *et al.* (2010) Impact of production systems on swine confinement buildings bioaerosols. *J Occup Environ Hyg*; 7: 94–102.
- Maghirang RG, Puma MC, Liu Y *et al.* (1997) Dust concentrations and particle size distribution in an enclosed swine nursery. *Trans ASAE*; 40: 749–54.
- Monso E, Riu E, Radon K *et al.* (2004) Chronic obstructive pulmonary disease in never-smoking animal farmers working inside confinement buildings. *Am J Ind Med*; 46: 357–62.
- Mount LE. (1975) The assessment of thermal environment in relation to pig production. *Livestock Prod Sci*; 2: 381–92.
- Olenchock SA. (1994) Health effects of biological agents: the role of endotoxins. *Appl Occup Environ Hyg*; 9: 62–64.
- Olenchock SA, May JJ, Pratt DS *et al.* (1987) Occupational exposures to airborne endotoxins in agriculture. In Watson SW, Levin J and Novitsky TJ, editors. *Detection of bacterial endotoxins with the Limulus amoebocyte lysate test*. New York: Alan R. Liss, Inc. pp. 475–87.
- OSHA. (2011) Occupational safety and health standards, subpart Z. Toxic and hazardous substances, 29 CFR 1910. Table Z-1 limits for air contaminants.
- O'Shaughnessy PT, Donham KJ, Peters TM *et al.* (2010) A task-specific assessment of swine worker exposure to airborne dust. *J Occup Environ Hyg*; 7: 7–13.
- Pedersen B, Iversen M, Larsen B *et al.* (1996) Pig farmers have signs of bronchial inflammation and increased numbers of lymphocytes and neutrophils in BAL fluid. *Eur Respir J*; 9: 524–30.
- Pickrell JA, Heber AJ, Murphy JP *et al.* (1993) Characterization of particles, ammonia and endotoxin in swine confinement operations. *Vet Hum Toxicol*; 35: 421–8.
- Preller L, Heedrik D, Boeij JSM *et al.* (1995) Lung function and chronic respiratory symptoms of pig farmers: focus on exposure to endotoxins and ammonia and use of disinfectants. *Occup Environ Med*; 52: 654–60.
- Reynolds SJ, Donham KJ, Whitten P *et al.* (1996) Longitudinal evaluation of dose-response relationships for environmental exposures and pulmonary function in swine production workers. *Am J Ind Med*; 29: 33–40.
- Reynolds SJ, Nakatsu J, Tillery M *et al.* (2009) Field and wind tunnel comparison of four aerosol samplers using agricultural dusts. *Ann Occup Hyg*; 53: 585–94.
- Robertson JF. (1993) Dust and ammonia concentrations in pig housing: the need to reduce maximum exposure limits. *Livestock Environment IV, Fourth International Symposium, Coventry, England, July 6–9*, pp. 694–9.
- Schwartz DA, Landas SK, Lassise DL *et al.* (1992) Airway injury in swine confinement workers. *Ann Intern Med*; 116: 630–5.
- Spanne M, Grzybowski P, Bohgard M. (1999) Collection efficiency for submicron particles of a commonly used impinger. *Am Ind Hyg Assoc J*; 60: 540–4.
- Thelin A, Tegler O, Rylander R. (1984) Lung reactions during poultry handling related to dust and bacterial endotoxin levels. *Eur J Respir Dis*; 65: 266–71.
- Thorne PS, Reynolds SJ, Milton DK *et al.* (1997) Field evaluation of endotoxin air sampling assay methods. *Am Ind Hyg Assoc J*; 58: 792–9.
- Vojta PJ, Friedman W, Marker DA *et al.* (2002) First National Survey of Lead and Allergens in Housing: survey design and methods for the allergen and endotoxin components. *Environ Health Perspect*; 110: 527–32.