Air quality in farrowing barns

P. C. CLARK and J. B. McQUITTY

Department of Agricultural Engineering, University of Alberta, Edmonton, Alta. T6G 2H1. *Received 30 October 1986, accepted 10 Aug. 1987*

Clark, P. C. and McQuitty, J. B. 1988. **Air quality in farrowing barns**. Can. Agric. Eng. **30**: 173–178. Concentrations and production rates of several major ambient contaminants were established in five farrowing rooms. Comparisons between three common flooring systems and between batch and continuous farrowing regimes were carried out. Total mean contaminant concentrations approached suggested limits although minimum ventilation rates recorded exceeded recommended values.

INTRODUCTION

Efficient and economic production of livestock and poultry under Western Canadian climatic conditions necessitates confinement housing for optimal animal growth and performance. Winter ventilation for moisture control is a common practice in confinement housing. Innovations such as heat exchangers and improved control techniques offer some relief from high energy costs during winter conditions, but reducing the ventilation rate obviously offers the greatest potential for reduction of the heat deficit and energy consumption. Such a reduction can lead to air quality concerns. Air quality, particularly important in the farrowing environment, increasingly has been recognized in recent years as playing a significant role in animal health and performance. Work in the occupational health field in the United States suggests that the combination of dust and gaseous contaminants found in such facilities poses a potential respiratory health hazard for workers particularly under winter conditions.

Current winter ventilation rate recommendations for farrowing barns are based on moisture control, and stem from work conducted in California over 30 yr ago in a psychrometric chamber capable of housing one sow and her litter (Bond et al. 1952). Such ventilation rates do not consider more recent improvements in genetic stock and management practices, nor the current knowledge of the adverse effects of environmental contaminants. There are, however, little definitive data available in Canada on air quality in swine facilities and apparently none with respect to farrowing units. If the benefits of potential energy savings measured in animal housing are not to be offset by increased health risks or decreases in animal performance, then benchmark concentrations of air contaminants in commercial facilities operated under different conditions and management practices must be established to insure an acceptable animal environment. The objective of the study was to report ambient concentrations and production rates for the purpose of establishing such benchmarks. Ambient moisture and particulate content, carbon dioxide (CO_2), ammonia (NH_3), and hydrogen sulfide (H_2S) were measured. The study was carried out concurrently with a study of heat and moisture loads in farrowing barns in Alberta (Clark and McQuitty 1986).

EXPERIMENTAL FACILITIES AND PROCEDURES

Five farrowing rooms were monitored in this study, four of which were an integral part of larger swine production facilities, but referred to as barns for the remainder of this paper. The weaning period was generally 4 wk in the barns studied. The building parameters of each barn are shown in Table I, including floor type and management practices. More detail of the experimental facilities has been reported elsewhere (Clark and McQuitty 1986).

Barn BS was a batch-farrowing facility with 0.6 m of perforated flooring across the rear of each crate covering a shallow manure pit, hereafter called a solid floor. Crates with totally solid floors were not studied. Barn BR, also a batch-farrowing operation, was a raised crate design to facilitate a comparison of the effect of floor type. Raised crates allow air to pass under a fully perforated floor and are used to facilitate handling of the sow and litter and to maintain a dry environment. Barn CR was also of raised crate design but utilized a continuous-farrowing system, allowing a comparison to be made between the two farrowing regimes. With the co-operation of the farmer involved in the study, Barn CR was monitored within the same building as Barn BR. The farrowing area of Barn BR was doubled to include two farrowing rooms while the sows in the rooms were reorganized to approximate a continuous-farrowing operation. This provided identical management practices, other than the system of farrowing, between Barns BR and CR, saved considerable time and cost in the monitoring process, and gave a better understanding of the operation of the environmental systems. To facilitate a further comparison, Barns CP and BP utilized fully perforated crate floors, with the farrowing management of the former being continuous and the latter the batch system.

Ventilation equipment is listed in Table I. A single variable-speed fan was utilized in Barns BS, BR, CP, and BP, while in Barn CR, two variable-speed fans were used. The primary supplemental heat source for all five barns was hot-water heating, with creep heating balanced by electric heating pads in Barn BS, hot water in Barns BR, CR and BP, and heat lamps in all five barns. The air entered Barn BS directly from an unheated attic through fixed inlets. Barns BR and CR utilized a preheated hallway, as well as hot-water pipes with an attached heat exchanger in each farrowing room. Barn CP utilized a center air inlet constructed in three separately adjustable sections. Finned copper pipe for heating purposes was placed in these sections. Barn BP had a preheated attic crawlspace with weighted polystyrene baffles forming the air inlet.

All five barns utilized pits under the entire perforated area of the crates (Table I). Barns BS, BR and CR utilized shallow

Table 1. Summary of barn operational characteristics

	Barn				
	BS	BR	CR	CP	BP
Farrowing regime	Batch	Batch	Continuous	Continuous	Batch
Floor type	Solid	Raised, perforated	Raised, perforated	Full perforated	Fully perforated
Number of crates	5	5	10	36	6
Pen area (m^2)	3.1	4.0	4.0	3.0	4.0
Perforations (% of floor)	42	100	100	100	100
Void area (% of perforated area)	26	47	47	26	45
Pit type	Shallow	Shallow	Shallow	Continuous Flow	Deep
Cleaning	Prior to batch	Prior to batch	Prior to monitoring	NA	Prior to batch
Fan size (mm)	461	305	2×305	457	400
Fan type	Variable	Variable	Variable	Variable	Variable
Inlet type	Fixed	Heated hallway	Heated hallway	Fixed	Weighted
Air pattern (inlet to fan)	Cross	Cross	Cross	Counter	Cross
Heating	Hotwater, electric pads, heat lamps	Hotwater, heat lamps	Hotwater, heat lamps	Hotwater, heat lamps	Hotwater, heat lamps
Feed type	Barley	Barley	Barley	Barley	Barley
Building construction	Wood frame, metal cladding				
Lights on/off	Continuous	———	Normally off	———	6:30-22:30
Feeding time	06:00 – 08:00 and 17:00 – 19:00 for all barns.				

pits which generally were cleaned at the beginning of a farrow-to-wean cycle. At the end of the batch cycle in Barn BR, the pits were filled to overflowing. Barn CP utilized a continuous-flow gutter, being the only barn monitored with the crates configured for such a system. Barn BP used a deep pit under the crates, which was emptied prior to the introduction of sows.

Data were collected for continuous 24-h periods throughout the farrow-to-wean cycle of the batch-farrowing facilities, or until a representative number of samples were obtained from barns utilizing a continuous-farrowing regime. Monitoring equipment was housed in a mobile environmental laboratory described by Feddes and McQuitty (1977, 1981) which provided an air-conditioned work area isolated from the farrowing barn environment. Multiconductor cables and gas-sample tubing ran from the barn to the trailer in a temperature-controlled conduit. Analog parameters and critical temperatures were sampled every four minutes, with the remainder of the temperatures sampled at 20-min intervals. These sampling frequencies were sufficiently fast to meet the requirements of time constants and the size of the 24-h data set. Table II describes the number, location and sampling period of each parameter.

The exhaust air temperature was recorded at three locations, each corresponding to one-third of the air flow through the single fan in the vertical plane. In Barn CR, the temperature was monitored at two locations at each of the two fans. At least one of the temperatures at the fan was monitored every four minutes (Table II). Each barn was divided into halves by length and a three-location temperature profile was monitored at the center of each half. The highest thermistors were placed 0.45 m from the ceiling, the mid-point thermistors at 1.2 m from the floor, and the low-level thermistors were fixed in place at 0.60 m from the floor to prevent interference by the piglets. Additional thermistors were placed 1.2 m from the floor approximately midway between the profile and the wall on each side for lateral temperature checks.

Gas concentrations and dewpoints were recorded from a different location every 4 min and always from the same location as a thermistor to ensure reliable reference temperatures for relative humidity calculations and manual humidity checks. Gas samples were drawn twice an hour from each fan location and from outside the barn. The remaining 4-min samples in each hour were drawn from ambient locations and inlet locations where necessary (Table II). Generally, two locations were samples at the level of the animals (0.6 m from the floor) twice per hour, and checks for dispersion across the room were made at two additional locations at least once per hour.

Supplemental heat was measured in each barn as described by Clark and McQuitty (1986). Ventilation and air movement were considered to be critical parameters. A calibration duct incorporating a flow straightener was constructed downstream of the exhaust fan or fans in each barn (Jorgenson 1983). A 25-point velocity profile was measured manually near the end of each duct at least twice daily and more often during variable weather conditions, and subsequently correlated to static pressure against which the fan was working, and to fan speed. Static pressure and fan speed were measured every 4 min. Fan speed was proportional to the frequency of pulses generated from Hall effect switches, which were triggered by a magnet attached to each fan shaft or hub. Smoke pencils were used to assist in air movement determination.

Infrared analyzers (Model 315A, Beckman, Fullerton, Calif.) were used to measure the NH_3 and CO_2 concentrations in the gas samples. Hydrogen sulfide was measured with a photometric total sulfur analyzer (Meloy Laboratories, Springfield, Va.). All the instruments were calibrated a minimum of twice during a 24-h data collection period, using certified span and zero gases (Matheson Gas Products, Canada). Dust was measured for a duration of 16 min of every hour in one representative location in each barn using a forward-scattering optical counter (Climet Instruments, Redlands, Calif.). The sample was drawn through an iso-kinetic tube for more uniform sampling of all

Table II. Data type, sensor placement and sampling period

Sensor description	Barn				
	BS	BR	CR	CP	BP
4-minute					
Fan RPM	1	1	2	1	1
Negative pressure	1	1	1	1	1
Fan temperature profile	3	1	1	2	3
Inlet temperature					3
Hot water temperature	4	8	8	4	
4-minute sequential gas samples, Dewpoint, NH_3, CO_2, H_2S†					
(times monitored/hour × number of locations)					
Fan profile	2×3	2×3	2×4	2×3	2×3
Inlet location		2			2
Ambient location	2×2	2×2	2×2	2×2	2×2
Outside	2×1	2×1	2×1	2×1	2×1
20-minute temperatures					
Outside/inlet	3	5	5	4	4
Ambient	10	11	11	10	10
Additional fan profile		2	3	1	

†H_2S was monitored for 1-h periods over 48 h.

particle sizes, and accelerated through a 6.35-mm outside-diameter tube for turbulent flow and minimal particle loss into the dust sampler. The Climet was calibrated by the manufacturer, and signaled calibration loss when grossly contaminated.

Experimental data describing each barn monitored on a run-dependent basis are shown in Table III. Hourly, daily and overall means were compared for farrowing crate floor type, and continuous versus batch farrowing regime. The overall means for the air quality parameters are tabulated in Table IV for each barn. The production rates of air quality contaminants were calculated on the basis of ventilation rates and the difference in concentration between the inlets and the exhaust fans. Ambient concentrations utilized the values measured in the vicinity of the pigs. Dust concentration was calculated on the basis of a 16-min sample period in each hour. The dust counter provided raw data in the form of 36-s counts of the total number of particles greater than five sizes (that is 0.5, 1.0, 2.0, 5.0 and 10.0 μm). The differences in the sequential numbers were the number of particles in each size range, and were subsequently grouped in size ranges greater and lesser than 5 μm diameter.

RESULTS

Ventilation rate and humidity

Current recommendations in Alberta are for a minimum winter ventilation rate of 7 L/s for each sow and litter and a rate of 14 L/s for a total winter ventilation rate, while the Midwest Plan Service (1983) recommends 9.5 L/s to control odors and moisture. This study found that Barns BR and CP had the lowest mean minimum ventilation rates of 15 and 14 L/(s.sow), respectively (Table IV). Hourly minimum ventilation rates fell as low

Table III. Summary of monitored parameter in each barn

	Barn				
	BS	BR	CR	CP	BP
Total runs	7	8	8	6	7
Monitoring start	27 Nov. 1984	6 Feb. 1985	19 Mar. 1985	18 Nov. 1985	16 Jan. 1986
Mean sow number	5	5	8.37	26.7	6
(Range)	NA	NA	(6/10)	(26/27)	NA
Piglet numbers (Range)	28/39	12/43	40/70	191/212	0/57
Piglet age (days)	NA	NA	18.43	16.86	NA
Range	1/19.9	1.7/28	NA	NA	0/24.2
Litter age (days)	0.8/22	0.4/27.8	NA	NA	0/29
Outside temperature (°C)					
Average	−8.3	−13.7	1.7	−12.1	−9.8
Range	−11/−3.9	−18/−9.5	−1.8/6.4	−17/−5	−14/−4.4
Ambient temperature (°C)					
Average	20.6	21.1	20.8	22.9	22.0
Range	19.3/21.8	20.4/21.9	19.8/21.8	22.0/23.6	21.7/22.5
Temperature differential (high-low, °C)	0.5	1.6	1.7	−0.6	−0.5
Static pressure differential (Pa)	−32	−50	−40	−15	−31
Ambient relative humidity (%)					
Average	35	59	54	50	37
Range	31/43	51/73	49/63	40/60	33/43
Total barn ventilation rate (L/s)					
Average	148	78	244	474	152
Range	125/171	74/82	208/300	374/623	129/179

Table IV. Total mean air quality parameters for each barn monitored (based on daily means)

	Barn				
	BS	BR	CR	CP	BP
Ventilation rate (L/(s. sow)					
Average	29	16	29	18	25
Range	25/34	15/16	25/35	14/24	22/30
Ambient NH_3 (ppm)					
Average	16	23	12	27	9
Range	10/20	14/33	4/20	20/33	5/15
Ambient CO_2 (ppm)					
Average	1745	2570	1746	2765	1802
Range	1400/2234	2195/3476	1366/2313	1921/3652	1375/2304
Ammonia (L/(h. sow))					
Average	1.7	1.2	1.3	1.4	0.8
Range	1.0/2.3	0.7/1.7	0.4/2.3	1.1/1.6	0.5/1.2
Carbon dioxide (L/(h. sow))					
Average	116	112	122	117	114
Range	88/152	89/170	90/162	92/150	83/155
Hydrogen sulfide (ppm)†					
Average	0.16	0.22	0.17	0.44	0.10
Dust concentrations (particles/mL)†					
Less than 5 μm	4.7	7.0	3.2	1.3	1.1
Greater than 5 μm	0.85	1.5	0.54	0.13	0.05

†Mean measured per barn.

as 12.2 L/(s.sow) and −20°C in Barn BR, run 4. In both Barns BR and CP, a ventilation rate in the order of 12 L/s per sow and litter allowed the relative humidity to approach approximately 60%. This is well below the 70–80% suggested in most extension literature as a maximum for a healthy environment and a dry barn (Midwest Plan Service 1983). However, the daily average CO_2 concentration approached, but did not exceed, the upper limit suggested by some agencies (American Conference of Governmental Industrial Hygienists (ACGIH) 1984; Scottish Farm Building Investigation Unit (SFBIU) 1984). Thus, air quality concerns lead the authors of this report to believe that 12 L/s per sow and litter may be an acceptable winter minimum ventilation rate for all the barns monitored. The actual ventilation rate generally exceeded this level (Table IV).

Air distribution was adequate in all test barns with very little temperature stratification occurring. Barns BR and CR, with large inlet openings from a heated hallway, had the largest differential in temperature, about 1.6°C, between the floor and ceiling. Barns CP and BP had a higher temperature near the floor than the ceiling by 0.5°C (Table III), which may have been as a result of radiant heating of the low level thermistors. The negative pressure was above the acceptable lower limit of 31 Pa for good air mixing (Turnbull and Bird 1981), in four barns. The pressure in Barn CP was −15 Pa. Here the greatest length of inlet, adjustable in three sections, created difficulty in obtaining the required negative pressure. Some short-circuiting between the end of the inlet and the fan was noted in the first two runs, after which the producer blocked the inlet closest to the fan, improving the static pressure by a factor of up to three for the remaining four runs.

Air Contaminants

Acceptable upper limits of air quality parameters in animal housing have yet to be firmly established. In the interim, occupational health standards (ACGIH 1984) for protection of humans against atmospheric contaminants in the industrial workplace often have been suggested as being appropriate of use as general guidelines for housed animals. These threshold limit values (TLV's), are 5000, 25, and 10 ppm for CO_2, NH_3, and H_2S, respectively (ACGIH 1984). TLV's are defined as a time-weighted average concentration for a normal 8-hour day/40-hour week. A report for the Commission Internationale du Génie Rural by the Scottish Farm Buildings Investigation Unit (SFBIU 1984) recommends maximum concentrations for CO_2, NH_3 and H_2S in animal housing of 3000, 20, and 0.5 ppm, respectively, with H_2S permitted to reach short-term exposures of 5 ppm during manure removal.

Ammonia

Concentrations for ammonia at the level of 50 and 75 ppm have been shown to decrease the pulmonary clearance of bacteria in swine (Drummond et al. 1978). The maximum recorded concentration in this study was 66 ppm for a period of 1 h. The daily average maximum was 56 ppm in Barn CP, run 1. The highest overall mean value was 27 ppm recorded in Barn CP with a mean range of 20–33 ppm. This is roughly equivalent to the suggested maximum NH_3 concentrations of 20 or 25 ppm.

Although all the NH_3 in a swine barn does not originate from under-floor manure storage, such storage does affect the concentrations found in the barn. The manure storage period in each barn generally was not longer than the weaning cycle of 4 wk, a factor which probably limited higher NH_3 production. Barn BR had the second highest NH_3 concentrations and the pit in the barn was not emptied on schedule. The minimum ventilation rates in Barns BR and CP were barely acceptable in terms of maintaining a sufficient dilution of NH_3 concentration. The production of NH_3 averaged 1.3 L/(h.sow) for all five barns, with the highest rate occurring in Barn BS at 1.7 L/(h.sow). Barn BS, however, did not have the highest concentrations, probably due to the relatively high ventilation rates.

Carbon dioxide

Carbon dioxide is generally a product of animal metabolism, although some may be generated from manure pits with long-term storage. The ambient concentration is, therefore, a function of ventilation rate and factors affecting animal metabolism

(Feddes et al. 1984). Utilizing 864 hourly mean values for each run of all five barns monitored, the ventilation rate (V) in L/s could be predicted in terms of the concentration (ppm) of CO_2 (C) at the exhaust fans as:

$$V = 65.03 - (2.797 \times 10^{-2} \times C) + (3.446 \times 10^{-6} \times C^2) \quad (R^2 = 0.79) \quad (1)$$

The TLV for CO_2 is 5000 ppm, while a suggested maximum for animal housing is 3000 ppm. A concentration of 5000 ppm was actually exceeded for 1 h in Barn CP, run 3, while hourly concentrations between 4000 and 5000 ppm were recorded several times in Barn BR and Barn CP, the barns where the actual ventilation rate was the closest to recommended minimum values.

Daily averages of CO_2 exceeded 3000 ppm only in selected runs in Barn CP. The highest overall means were found in Barns BR and CP and both were below 3000 ppm. The minimum ventilation rate measured was effective in maintaining acceptable levels of contaminants.

The production of CO_2 will vary with the amount of feed consumed and the efficiency of metabolism, and can vary even among sows of the same size. Diurnal fluctuations of the calculated values for CO_2 production were as much as 50–200% of the total mean value, but since production is calculated as a function of ventilation rate, the actual production must be calculated over a longer time period. The production of CO_2 in this study averaged 116 L/(h.sow) with a variation of plus or minus 10 L/(h.sow) on a daily basis.

Hydrogen sulfide

Periodic sampling of H_2S yielded only traces (Table IV). No correlation appeared to exist between concentration and manure management system, or age of litter. Hand sampling with chemical tubes showed traces up to 1 ppm. The peak concentration recorded occurred in Barn CR, run 6, with a reading of 0.63 ppm ambient, and 0.8 ppm below the slats. The highest mean H_2S value per barn was measured in Barn CP, where a continuous-flow gutter system was used. High sulfate levels in the water, which can increase the potential for H_2S generation (Donham et al. 1985), may have been a factor.

Dust

Aerosols of sizes less than 5 μm are classified as respirable dust (Hinds 1982), with the most dangerous size range being those particulates less than 2 μm. In no instance did the total dust concentration (Table IV) exceed the suggested threshold limit values of 1050 or 420 particles/mL for nuisance particulates or grain dust, respectively. The effect on animals of continuous exposure to dust concentrations, in combination with other ambient contaminants such as those found in this study, is unknown. Some studies have shown an inhibition of respiratory defenses, including a loss of cilia, in animals subjected to the complex aerosols found in confinement swine barns (Donham and Leininger 1984).

In terms of human health, the researchers in this study found that brief exposures to the atmosphere in the barns frequently led to coughing and congestion for some hours afterwards. The operators of the units did not find the same to be true, suggesting that some adaptation to the environments is developed through long-term exposure. The effects of these environments are not known over the long-term, although the documentation of TLV's (ACGIH 1984) states that they do not apply to lower limits which may cause physiological disability.

Curtis et al. (1975) indicated that airborne bacteria colony forming particles (BCFP's) were directly related to dust levels. In one study in Iowa, Donham et al. (1984) found 91% of confinement workers reported adverse effects, 75% with bronchitic-like symptoms, and 33% with delayed symptoms. After 2 yr in the industry, the effects among workers were often chronic. Smoking caused additive effects. The workers in their study had an average experience of 6.2 yr working in intensive livestock housing. Since confinement housing practice can be considered recent, the long-term effects of working in such environments should be monitored closely.

This study found that the aerosol concentrations exhibited large daily fluctuations as a result of animal activity and ventilation rates. Particles of sizes larger than 5 μm were not present in large quantities in any of the barns monitored. Particles of size less than 5 μm reached a maximum daily concentration of 9.1/mL, with Barn BR being the dustiest with a total mean of 7.0/mL. In all runs, the number of particles in the ranges of 0.5–1, 1–2, and 2–5 μm were of about equal orders of magnitude. The size ranges of 5–10 and greater than 10 μm contained fewer particles in all cases, often by a factor of 10.

Results were inconclusive when comparing batch versus continuous farrowing regime. Of the three barns operated under the batch system, the first run monitored in Barns BS and BR had the lowest dust concentrations recorded in those barns. Barn BP had consistently lower concentrations. However, the operator of Barn BP utilized canola oil in the feed to reduce the dust levels in the barn. Of the three barns, Barn BP had the lowest relative humidity, and an intermediate ventilation rate per animal unit, suggesting that the canola oil may have influenced the production of aerosols. Of the two continuous farrowing barns, Barn CP had concentrations consistently lower than those found in Barn CR. No reason for the difference was evident, and the particle concentrations appeared to be dependent on ventilation rate.

SUMMARY AND CONCLUSIONS

The following summary of results and related conclusions can be drawn from this study:

(1) The effects of batch or continuous farrowing systems or of flooring type on air quality parameters were not apparent in this study.

(2) The minimum ventilation rates recorded were higher than recommended values, but resulted in concentrations near those suggested for some air contaminants.

(3) Humidity and temperature were controlled adequately in all five barns, with relative humidity generally well below the suggested maximum levels.

(4) The ambient concentrations of CO_2 averaged 2105 ppm for all five barns. Daily concentrations ranged from 1380 to 3591 ppm and hourly means were as high as 5000 ppm in one barn.

(5) The production of CO_2 averaged 116 L/(h.sow) for all five barns ranging from 112 to 122 L/(h.sow) between barns and the daily mean for all five barns ranging from 104 to 138 L/(h.sow).

(6) The exhaust concentration of CO_2, on an hourly basis, could be used to determine the ventilation rate per sow and litter with a degree of fit (R^2) as high as 0.79.

(7) Ammonia concentrations ranged from almost 0 to a high of 66 ppm for one hourly period. For the five barns monitored, the overall mean NH_3 concentrations per barn ranged from 9 to 27 ppm and averaged 17.4 ppm.

(8) The production rate of NH_3 ranged from 0.8 to 1.7 L/(h.sow) in the five barns monitored, and averaged 1.3 L/(h.sow).

(9) The concentrations of H_2S reached only trace levels in the five barns monitored, the maximum mean value per barn being only 0.44 ppm.

(10) Dust did not reach the suggested threshold limit values for either grain dust or nuisance particulates, with the overall mean per barn ranging from 1.1 to 7.0 particles/mL (<5 μm) for the five barns monitored.

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