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HIGH-RISE ™ HOG FACILITY

R. R. Stowell, H. Keener, D. Elwell, T. Menke, and S. Foster[1]

ABSTRACT

The design concepts of the High-Rise ™ swine facility are presented along with thermal conditions, gas levels and airflow patterns within an instrumented finishing facility during its first four growouts (1998-99). The High-Rise ™ facility is a two-story, above-ground structure that utilizes a drying plenum and a special ventilation strategy to produce smaller manure volume and manure that can be handled as a solid, while using pens with conventional slatted-floors. The novel ventilation system kept the mean air temperature within the pig space within a narrow band (± 1 ^{o}C) around the desired temperature. Air temperatures from one end of the facility to the other differed by up to 5.5 ^{o}C during cold weather extremes although the temperatures at the given locations were fairly constant. Measured ammonia concentrations in the pig space averaged 4.3 ppm with no readings exceeding 20 ppm. Ammonia concentrations in the lower story averaged 21.8 ppm with readings regularly exceeding 20 ppm during cooler months. Hydrogen sulfide levels in the facility were consistently below 1 ppm. Carbon dioxide readings averaged 1,270 ppm in the pig space. The manure mixture produced through the addition of bedding material and aeration was removed from the facility using a front-end loader. The average moisture content of this material ranged from 45-68% following clean-outs.

KEYWORDS: Swine housing, Aerial environment, Airflow, Manure handling, Solid manure.

BACKGROUND

Environmental, neighbor and economic pressures have encouraged swine producers to investigate options for housing their animals. One recent development in swine housing is the High-Rise ™

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concept. This housing system was designed to solidify hog manure within a slatted-floor production facility. A second goal was to improve the quality of air within the animal environment and around the building – with the expected results being improved pig performance and less potential for neighbor complaints about odor. Mescher et al. (1999) described the background of the High-Rise™ facility in greater detail. Unlike most of the swine production facility designs implemented over the years, advances in labor efficiency, improvements in pig performance, or reductions in construction cost did not drive the design, although each was considered to be important. The result was intended to be a unique design that was competitive with other facilities on a total system basis, but would be more desirable from an environmental standpoint.

SYSTEM DESIGN AND DESCRIPTION

4-M Farms built the first High-Rise™ hog facility (Fig. 1) in Darke County, Ohio in 1997-98 with a capital-improvements (construction) grant from the Ohio Department of Administrative Services. This demonstration/research building was built to test the concept of the facility's design, in which manure at 90% moisture would be partially stabilized and dried to 30-40% in place on a bed of bulking agents. The first batch of hogs was placed in the facility in July 1998.

Figure 1. 4-M Farms High-Rise™ Hog Building – Research / Demonstration Facility.

The design of this facility incorporates several significant variations on concepts of high-rise layer (poultry) facilities, one of the most significant being an aeration system, which is used to aerate, dry, and solidify the manure. Pigs are housed in the upper story on slats. A layer of bulking material is placed in the lower story before pigs are brought into the facility. Manure falls through the slatted flooring, into the lower story, and onto the bed of bulking material. The bulking material adsorbs liquids, contains the manure, and allows air to flow through the bed from below. Once moistened air leaves the bed, it combines with ventilation air supplied to the pigs and is exhausted by fans located in sidewalls of the lower story.

<u>Construction Features</u>

The most visible difference between a High-Rise™ facility and conventional swine production facilities is that the structure is taller. The floor of the lower story is constructed at ground level. No pit is constructed into the ground meaning excavation requirements are reduced. Large access doors are included in the sidewalls of the structure to allow implements access into the lower story. A ramp must be constructed to facilitate loading and unloading pigs.

These buildings carry additional wind load due to their increased height. The walls are designed as standing rather than retaining walls. Lateral forces on the lower walls are reduced since the pressure exerted by about a meter of solid manure is significantly less than that of 2-3 m of potentially saturated earth. One or more rows of columns support the slats and the contents of the upper story. In this facility, achieving reasonable clearance height in the lower story is desirable to enable wheeled implements to access the entire area. Since no agitation (of liquid manure) is involved, a clear span over the lower story is not required. The number of columns used and their placement can significantly restrict access to the manure-laden bedding, however.

Tilt-up wall sections can be used in the construction of these facilities. Because requirements for containing liquids are much less extensive with this design, only the lower portion (few feet) of the sidewalls needs to be constructed water-tight. Construction must provide for installation of the aeration system, especially the in-floor plenum (system of air ducts). Other construction features are similar to those for conventional slatted-floor facilities.

Aeration System

The aeration system was designed to remove moisture from manure generated by swine over their growth period, in this case for finishing pigs raised from 18 to 110 kg (40 to 250 lb.). The system was also designed to achieve uniform airflow regardless of the depth or moisture level of the drying bed. Keener et al. (1999) describe the design of the aeration system in greater detail.

The floor area of the research/demonstration facility was divided into 4 zones with each zone having its own fan system (Fig. 2). The floor of this facility is 13.7 m x 61 m (45' x 200'), and each of the four zones is 6.1 m x 30.5 m (20' x 100'). The design airflow rate for this facility was calculated to be 3.1 m^3/s (6,500 cfm) or 0.77 m^3/s (1,625 cfm) per zone.

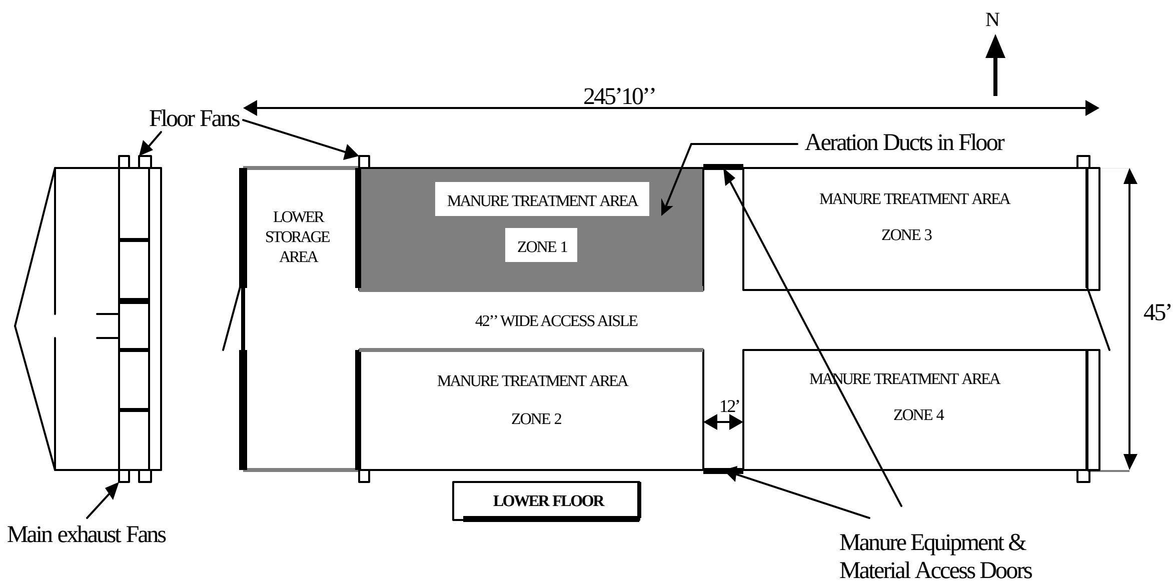

Figure 2. Schematic of lower-story floor for the 4-M Farms High-Rise™ Hog Building with drying zones identified.

Piping for distributing air was installed below the floor to avoid interference with equipment during manure removal. Pipes were spaced 0.76 m (2.5 ft) on center – the design spacing for an aeration bed 0.45-0.60 m (1.5-2 ft) deep. This spacing would maintain the same airflow path distance from a bed's air inlets to the upper surface of the drying bed. The final design used a limited number of openings of a specific size in the pipe to prevent short-circuiting of air, which would become a concern when manure accumulated on the drying bed. This concept had been incorporated into in-vessel composting systems in the Netherlands (Hoitink and Keener, 1995).

Ventilation System

The ventilation system is distinctly different from those of conventional (deep pit or shallow pit w/flush) swine finishing facilities in that all exhaust fans are located in the lower story of the building (Fig. 3). Air is drawn into the building through attic openings. In the research / demonstration facility, air is brought in through openings in the endwalls and along the ridge. In the commercial buildings, air is brought in through nearly continuous eave and ridge inlets. Tempered air is withdrawn from the attic into the pig space through baffled ceiling inlets. Typically, one inlet on each side runs almost the length of the production room. This design directs jets of air outward from the room inlets along the ceiling of the room. Fresh air mixes with room air (rotational flow) prior to being drawn through the slatted flooring into the lower story. Since the upper story is airtight other than the ceiling inlets and slatted flooring, the bulk movement of air is downward, with ventilation air moving into the lower story before being exhausted.

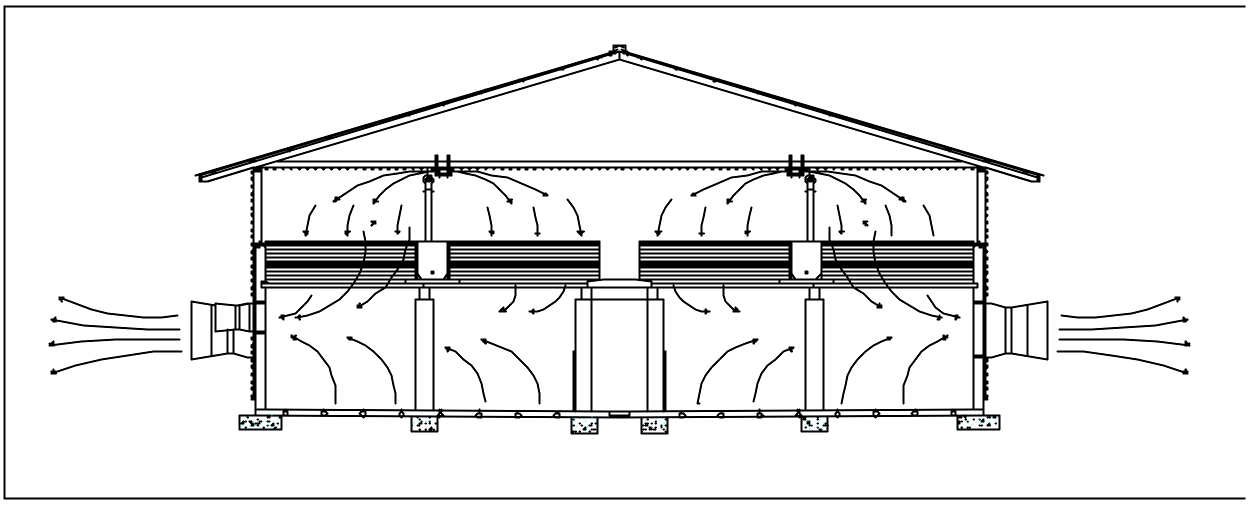

Figure 3. Design airflow patterns within a High-Rise™ swine finishing facility (4M Farms research /demonstration facility).

MATERIALS AND METHODS

The research / demonstration facility included modern monitoring and control systems for maintaining desired temperatures within the pig space. Indoor (upper story) and outdoor dry-bulb air temperatures, dry-bulb air temperatures at eight locations distributed evenly around the pig space, and fan operation data were collected on a nearly continuous basis. The main environmental control system recorded representative air temperatures and fan operation every half-hour. Type-T thermocouples were placed to sense the air temperature 1.2 m below the ceiling of the pig space at eight locations, which represented evenly distributed sections of the facility. A datalogger (Campbell Scientific, model 21X, Logan, UT) received the output of the thermocouples. The datalogger was connected to the facility's computer system, which allowed monitoring of the data on-site or via file transfer. Typically, data was downloaded onto a diskette during visits to the site and analyzed using a spreadsheet package (Microsoft® Excel 97, v. 6.1).

Gas measurements were taken at three locations within each story and from the exhaust of three fans located around the building perimeter (Fig. 4) using Dräger tubes. Gas measurements were taken approximately every two weeks during each growing period at approximately noon. Gas readings were taken at belt height (roughly 1 m off the floor), just above a pen's hallway gate in the pig space. Horizontal and vertical locations of gas measurements were similar for the lower story, given that the readings were taken 1 m above the drying bed surface (depth approximately 0.6 m) rather than the floor. An aspirated psychrometer was used to record wet- and dry-bulb temperatures at each of the interior sampling locations at the time the gas readings were taken.

To maintain a reasonable level of biosecurity, readings were always taken and observations made from within the pig space (upper floor) prior to entering the lower story. Additionally, standard practices of not visiting other swine farms in the days prior to a visit, using only equipment that was sanitized or remained on-site, and wearing disposable coveralls, etc., were followed. For safety reasons, two individuals were always present during the visit, particularly when taking readings from within the lower story. A respirator was located close to the access door. Typically, gas sampling required 20-30 minutes per story to complete. Outdoor air temperature, wind speed and direction, and weather conditions were recorded. Observations were made using smoke sticks (E. Vernon Hill, Benicia, CA) and a hand-held vanometer. Photographs were taken to document conditions and any unusual activity.

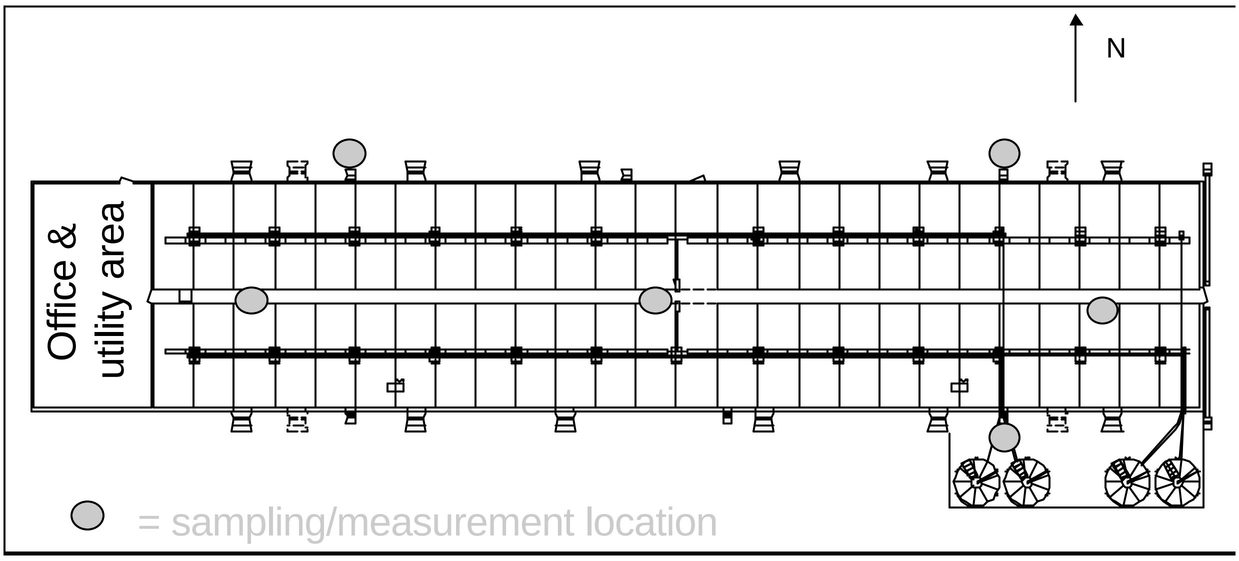

Figure 4. Gas measurement locations on a plan view of research / demonstration facility.

RESULTS AND DISCUSSION

<u>Thermal Environment of Pig Space</u>

Average air temperatures within the upper story were maintained within a fairly narrow band around the desired indoor temperature during cool and cold weather - ±1 ^{o}C (±2 ^{o}F) during 10 ^{o}C swings in outdoor temperature as shown in Fig. 5. Individual temperatures throughout the pig space were also quite stable. However, there was considerable variation within these individual temperatures. Most of the variation (up to 5.5 ^{o}C) occurred along the length of the building. The operator noted that during these times, wind pressure on inlet openings at one or the other of the endwalls was a strong suspect in causing this variation. Also, the two heating units were controlled jointly based on a central temperature reading, which likely prevented the heating units from balancing out the room temperature. Variation in temperature was reduced when outdoor temperature rose. Interior temperatures during summer were very similar – to the extent that a plot of individual temperatures was displayed as a band of indistinguishable lines (not shown).

<u>Measured Gas Levels</u>

<u>Ammonia.</u> Measured concentrations of ammonia within the pig space were consistently below 20 ppm which is the 8-hour exposure threshold limit (ACGIH, 1984) for building occupants. The average concentration was 4.3 ppm (Table 1) and readings ranged from undetectable to 19 ppm. Jacobson et al. (1996) reported that ammonia concentrations in the pig space of twenty-six conventional finishing facilities typically ranged from about 5 ppm during summer to 10-20 ppm during winter. More modern, intensively managed facilities exhibited higher concentrations.

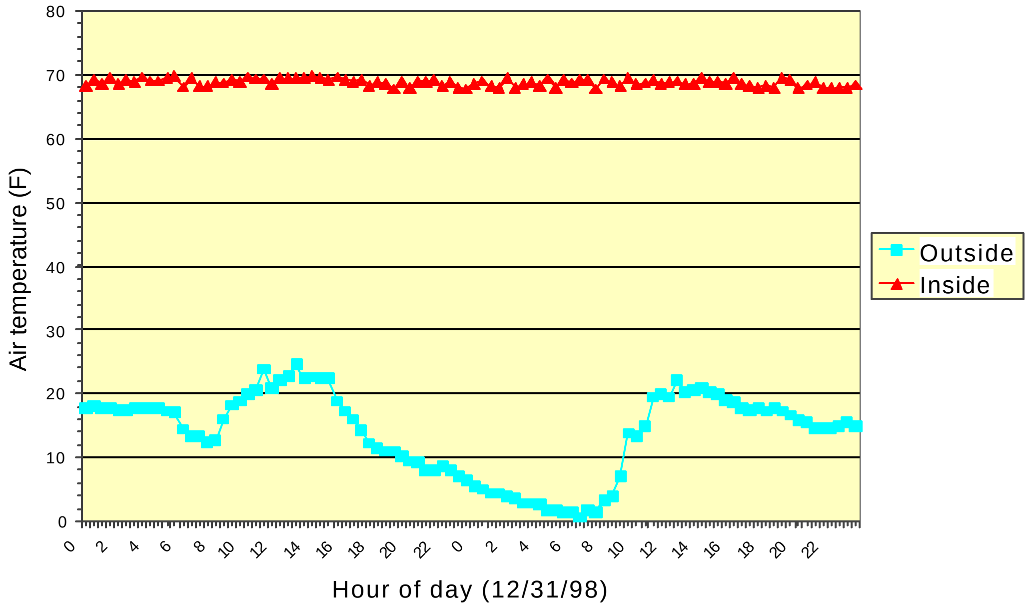

Figure 5. Mean air temperature in the pig space of the High-Rise™ finishing facility compared to outdoor temperature during a representative period of cold weather.

Table 2. Summary of Environmental Measurements at the High-Rise™ Research / Demonstration Facility during 27 Site Visits over a 18-Month Period.

Measurement	Average	St. Dev.	Minimum	Date occurred	Maximum	Date occurred
Dry-bulb temperature	(°C)	(°C)	(°C)		(°C)	
Upper story	22.4	3.5	14.4	12/7/99	36.1	7/30/99
Lower story	20.7	5.4	9.4	12/21/98	35.6	7/30/99
Outdoor	16.5	9.1	-2.8	12/21/99	35.0	7/30/99
Wet-bulb temperature	(°C)	(°C)	(°C)		(°C)	
Upper story	17.3	3.9	11.7	12/21/99	29.2	7/30/99
Lower story	16.3	5.1	7.2	12/21/99	29.2	7/30/99
Outdoor	12.5	8.2	-3.9	12/21/99	28.9	7/30/99
Ammonia concentration	(ppm)	(ppm)	(ppm)		(ppm)	
Upper story	4.3	3.3	0	5 dates	19	1/19/99
Lower story	21.8	18.3	0	9/3/98 7/1/99	136	2/9/99
Exhaust[a]	17.9	14.8	1	4/30 & 7/14/99	84	12/7/99
Hydrogen sulfide[b] concentration	(ppm)	(ppm)	(ppm)		(ppm)	
Upper story	0.0	0.0	0	All visits	0	All visits
Lower story	< 0.1	< 0.1	0	Many visits	0.3	6/2/99
Exhaust	< 0.1	< 0.1	0	Most visits	< 0.2	6/2 & 6/16/99
Carbon dioxide[c] concentration	(ppm)	(ppm)	(ppm)		(ppm)	
Upper story	1,270	1,041	0	7/30/99	3,950	3/16/99
Lower story	1,150	302	200	4/2/99	2,200	7/30/99
Exhaust	970	150	440	7/1//99	2,150	4/30/99

a	Readings of exhaust air concentrations were initiated in October, 1998.
b	No H_2S measurements were taken prior to 9/18/98.
c	CO_2 measurements were begun on 3/16/99.

Concentrations of ammonia within the lower story regularly exceeded this limit with one reading from the west sampling location exceeding 120 ppm. The average concentration downstairs was 23.3 ppm. Readings taken from the regions of the building nearer the endwalls were consistently higher than were those taken at the center of the building. In many production facilities, the pens near the ends of the building are not ventilated as well as the pens in the mid-section. This facility had additional features that may have led these measurements to have higher-than-average readings. The western end of the building was dedicated for office space, people facilities, and utilities, which precluded placing fans in or near the endwall. The ceiling inlets stopped short of running the entire length of the pig space by almost 2 m on each end, limiting somewhat delivery of air to those regions. Also, the operator felt that if the wind was directly out of the east or west (at an endwall), airflow was elevated in the leeward sections of the building and some rotational flow of air in the longitudinal direction was occurring (not able to document).

The pronounced trend was for ammonia levels to increase during cold weather when ventilation rates were at a minimum, as shown in Fig. 6. The increased rate of ammonia generation under slightly warmer conditions (2-5 ^oC difference noted between summer and winter) was more than offset by highly elevated rates of ventilation. Ammonia was difficult to detect in the upper story during visits on hot summer days. The ammonia intensity could be visually estimated throughout the year by noting the condition of the slatted flooring. Ammonia release is a surface phenomenon that is enhanced at air/water interfaces, so maintaining drier slats should be of benefit.

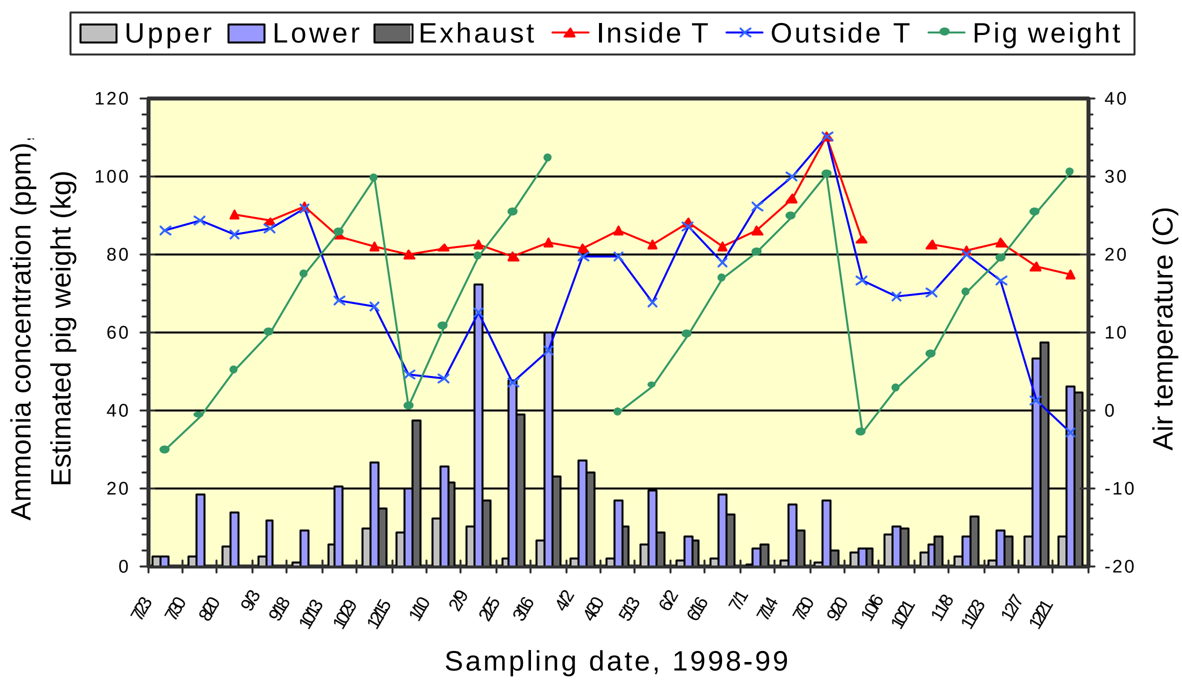

Figure 6. Ammonia concentrations within the pig space of the High-Rise^{TM} research / demonstration finishing facility by sampling date and sampling location.

Ammonia levels in the lower story were considerably higher (by a factor of 2-10) than those in the pig space. The lower story is "downstream" in this ventilation system – any contaminants picked up by the air as it travels through the pig space were carried downstairs. Additionally, air that was moved through the manure aeration system was likely laden with ammonia, and this air mixed with the air from the main ventilation system in the lower story. The ammonia levels within the lower story were irritating during late winter, causing watery eyes, odor, and slight respiratory distress when the area was occupied for several minutes.

Mean exhaust air concentrations were 19.9, 15.6 and 18.1 ppm for the northwest, northeast and southeast fan locations, respectively, with an overall mean of 17.9 ppm. Mean concentrations of ammonia in exhaust air were typically 10-50% lower than were the concentrations within the lower story of the building for a given sampling date. One explanation for this finding is that the fans exhausted some of the relatively fresher air that passed through the slatted flooring before that air reached the more interior regions of the lower story.

Hydrogen sulfide. Hydrogen sulfide was difficult to measure or detect within the pig space (Table 1). Occasionally, hydrogen sulfide was barely detected at concentrations not exceeding 0.5 ppm downstairs. The detectable hydrogen sulfide readings occurred within a few days of when the bed was mixed. The data collected were insufficient, however, to suggest that hydrogen sulfide was never present at hazardous levels in the manure storage area of this facility, nor that operators do not need to be concerned about being overcome by manure gases.

Traces of hydrogen sulfide were detected in the exhaust air of this facility on only a few occasions (Table 2). As H_2S is an odorous gas (rotten-egg smell), the consistently low concentrations of hydrogen sulfide in the exhaust air bode well for addressing concerns about odor.

Carbon dioxide. Measured concentrations averaged 1,270; 1,150 and 970 ppm for the upper story, lower story and exhaust air, respectively (Table 1). Measurement of CO_2 was not initiated until the spring of 1999. Carbon dioxide is a product of respiration and its presence in the pig space was expected. All readings were within the maximum allowable concentration of 5,000 ppm (MWPS, 1990).

Airflow Patterns

The bulk movement of air was documented to be as designed (Figure 3) by observing the movement of smoke. Air entered the upper story via the ceiling inlets, traveled as a jet along the underside of the ceiling, and demonstrated the basic rotational pattern typical of this inlet configuration. Considerable air was pulled toward the slatted floor before making a full rotational cycle, however. Mixing of the fresh air with room air took place rapidly once the fresh air curved away from the ceiling.

In the lower story, a well-defined interface existed as a horizontal plane between air that arose from the aeration bed / manure mixture and air that was drawn downward through the slatted flooring. During cold weather, this interface was positioned about 0.5-1 m (2-3 ft) below the bottom of the slats. During summer, the interface was inverted, existing at a similar distance above the surface of the manure mixture. Typically, air remained within a region surrounding this interface, with little upward or downward movement observed, until it was expelled from the building by an exhaust fan. The number and location of fans operating affected airflow patterns within the lower story. Air moved downward through the slatted flooring during summer conditions. During cooler conditions, especially when minimum ventilation was provided, air/smoke moved along the underside of slats in some regions and pockets existed where this air was drawn up through the slots into the pig space.

In the High-Rise^{TM} system, aerodynamic forces differ from those in conventional facilities. Airflow over slats creates a suction that can draw air up into the pig space, and pit ventilation may increase gas release from the liquid manure surface in the pit into the headspace (Fisher and DeShazer, 1972, etc.). These phenomena favor the new facility design. On the other hand, decomposition of manure in the lower story generates manure gases, such as ammonia, and aeration may encourage movement of air from the lower story into the pig space during minimum ventilation. More study is needed to document the effects of airflow patterns in these facilities on air quality and pig performance.

Operational Considerations

Drying bed management. The aeration fans were operated nearly continuously and drew entirely fresh air in the research and demonstration facility. Those involved in studying this facility generally agreed that the system did not need to operate at full capacity during the first few weeks of a growout when the beds were dry and the pigs were small. During cold weather, aeration with outdoor air did not accomplish a high rate of drying, but noticeably elevated the ventilation rate required and heating needs in the pig space. Commercial building plans were revised to allow intake air for the aeration system to be drawn from within the facility (recirculation). The results of this change still need to be determined.

Wood shavings and corn stover have performed well as bulking materials, especially in terms of maintaining their porosity. Sawdust and shredded newspaper have not performed well in spot trials because the surfaces of both materials matted over quickly, resulting in poor flow of manure downward and air upward. Chopped straw was assessed to be acceptable as a bulking agent. Analysis of data on the compositions of the manure-laden bed materials is in progress.

Bed material from one quadrant was recycled twice, meaning it was used for three growouts or for about a year. After mixing, the material was allowed to heat for a few days, was leveled off, and a layer of fresh material was applied to the upper surface. At the end of the third growout, about 0.75-0.9 m (2.5-3 ft.) of material remained. On a volume basis, there was about 65% less material to transport and utilize as compared to liquid manure in a deep pit. Most of the manure-laden bed material is currently being composted on site.

Although considerable drying of the bed material took place, in-situ composting did not occur without mixing. The normal inactivity and activity following mixing were documented using temperature probes. The design of the research/demonstration facility did not accommodate the pigs' dunging patterns well. The pigs' natural social habits led them to dung near the fronts and backs of the pens. In this facility with a central alley, manure was deposited along the outer wall and next to rows of support columns, which was undesirable from both a drying and handling standpoint. The design of the commercial facilities was revised to incorporate outside alleys and only two rows of support columns (Fig. 7). A mixing device has been developed for use in the facilities and the effect of its use is currently being evaluated.

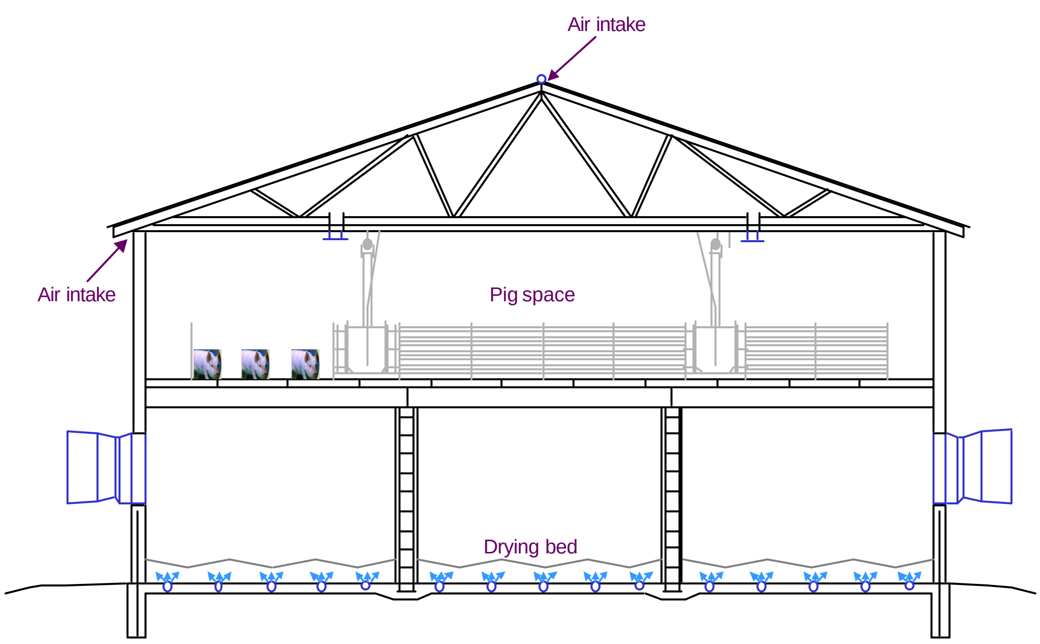

Figure 7. Cross-section view of commercial version of High-Rise™ finishing facility.

<u>Pig Performance</u>

Evaluation of pig performance is in progress. On a gross basis, the four groups of hogs raised in the research/demonstration facility have had similar or better growth rates than hogs raised in ten conventional facilities under the same contractor. Variations in market weights and other potential variables must be considered, however, before more a more definitive assessment can be made.

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