VENTILATION REQUIREMENTS TO PREVENT PIT AIR UP-DRAFTING IN A SWINE FINISHING BARN

R. Nicolai, and S. Hoff

ABSTRACT

Curtain sided deep-pit swine finishing buildings are popular in the industry due to concerns related to odors from outdoor manure storage systems. Local regulators are requesting additional odor reduction from the building. Biofiltration is a technology that reduces odors exhausted from swine buildings if the exhaust air can be controlled. Upward air movement through the slatted floor must be eliminated to treat all pit gasses when the ventilation is operating in a mode with the curtains lowered.

Critical (minimal) pit ventilation rates were determined to insure downward air flow through the slatted floor in a swine finishing barn with 8, 11, 14, 17, 20, 23, and 36 percent floor opening. The critical air velocity through the slatted floor averaged 36.2 ft/min (SD = 1.2 ft/min).

Using a safety factor of 1.5, the design criterion is 50 cfm/pig for pit ventilation rate before the curtains are lowered for full-slatted barns to assure no upward air movement from the pit after the curtains are lowered. This recommendation will provide continuous biofilter treatment of pit gasses for all ventilation modes.

Keywords. Air quality, Pit ventilation, Slatted floors, Swine housing.

INTRODUCTION

Odor from swine finishing buildings has been a problem that is receiving increased attention. An effective technology to remove up to 90 percent of the odor from mechanically ventilated swine buildings is biofiltration (Nicolai and Janni, 2000). Adapting a biofilter to a curtain sided deep pit totally slatted swine finishing barn is a challenge. During the summer ventilation mode with the curtains lowered or opened, the exhaust air is not controlled and is dependent upon the wind. Also, with very little or no pressure drop across the slatted floor, parts of the barn experience up-drafting due to buoyancy while in other areas air is moving down through the slats. Thus pit gasses can rise to the pig environment zone and exhausted uncontrolled through the open curtain.

To achieve pit gas odor reduction through biofiltration, up-drafting through the slatted floor must be eliminated when the curtains are lowered. For common fully-slatted pig grow-finish houses a 6-8 inch wide slat is used with a recommended 1 inch spacing (MWPS, 1991) resulting in a floor opening ranging between 11 to 14 percent.

Floor design has been shown to affect the air distribution in an enclosed building. Grub et al. (1975) found the width of the slots in a slatted floor (percent opening) affects the down-draft performance of an annex type of pit ventilation. Buller and Hellickson (1978) found that the amount of slatted flooring in a pit-ventilated building affected air velocities at the animal level; however, there was no effect at the pit level.

Hoff (1998) evaluated pit head-space ventilation in swine barns. The study investigated back-draft control in the head-space region using airflow visualization techniques in a full-scale, experimentally controlled swine finishing barn. Critical airflow requirements were determined to maintain down-draft through floors slats for openings from 4 to 8 %. A linear relation was found

between critical head-space ventilation rate and percent floor opening (PFO), where $(\text{cfm/pig})_{\text{critical}} = 1.92 * \text{PFO} - 1.92$. The percent opening range used in the derivation of the linear relation does not include most standard design finishing barns, i.e. 11 to 14 %.

The purpose of this paper is to determine the minimum ventilation rate required to maintain a positive pressure drop thus preventing up-drafting across totally slatted floors with openings from 8 to 36%.

MATERIALS AND METHOD INTRODUCTION

The study was conducted at the Air Dispersion Laboratory (ADL) at Iowa State University. This laboratory utilizes a full-scale section of a typical swine confinement building to model and to control the conditions in a swine barn (Hoff et al., 2000). The section used for this experiment is 21 ft long by 24 ft. wide. It includes counter balance ceiling inlets and a 2 ft. pit head space region below the perforated plastic flooring. The head-space region was fitted with both a plenum exhaust system and a direct outlet fan exhaust system. The center 2 ft walk-way serves as a central plenum with 4 in diameter holes spaced at 14 in centers for testing pit-ventilation. Low airflows, i.e. for floor openings < 8%, were conducted utilizing the plenum exhaust system. Higher airflow tests were conducted utilizing the direct exhaust system because of added restriction through the plenum and its fan capacity.

Pit ventilation rate was adjusted with a matched variable speed controller. Room airflow rate was determined using a calibrated attic inlet system. Percent floor opening was adjusted using flexible rubber mats to cover desired areas of the floor. Floor openings investigated were 8, 11, 14, 17, 20, 23, and 36 percent.

Down-draft verses up-draft conditions were determined using a visualization technique. Several smoke sticks (Model 15-049, E. Vernon Hill, Inc) were strategically placed above the floor. A 5 minute conditioning period after fan start-up was used to achieve steady-state conditions. The smoke sticks were then observed for two minutes for flow direction. During the observation period at or near the critical airflow between up-draft and down-draft, the smoke would be mostly down-drafted. Occasionally an up-draft puff of smoke would occur. If none or only one up-draft event was observed during the two minute observation period, the airflow was considered to be above the critical value, i.e. no up-drafting. If two or more up-draft events occurred during the two minute observation period, the airflow was determined to fail the down-draft criteria.

The following procedures were used to determine the minimum airflow to prevent up-drafting:

- Set-up flooring for the desired percent opening.

- An airflow rate was selected by setting the variable speed control of the pit-exhaust fan.

- Visualization was conducted for two minutes after a five minute conditioning period to determine up-drafting verses down-drafting.

- This process was repeated for several airflows both greater than and less than the airflow to achieve the complete down-draft criteria.

- Percent floor opening was adjusted and the above procedure repeated.

- Two replications of each setting were completed.

RESULTS AND DISCUSSION

Figure 1 shows the results of determining the critical airflow for various percent slatted floor openings to the pit head space. Airflow trials that failed the criteria or exhibited up-drafting are shown with a diamond legend and those trials that passed are shown with a square legend. For a given percent floor opening there was a definitive transition for airflows that passed or failed the

visual criteria that was applied to the smoke direction test; i.e. airflows less than the critical value all failed, whereas airflows greater than critical all pass the criteria.
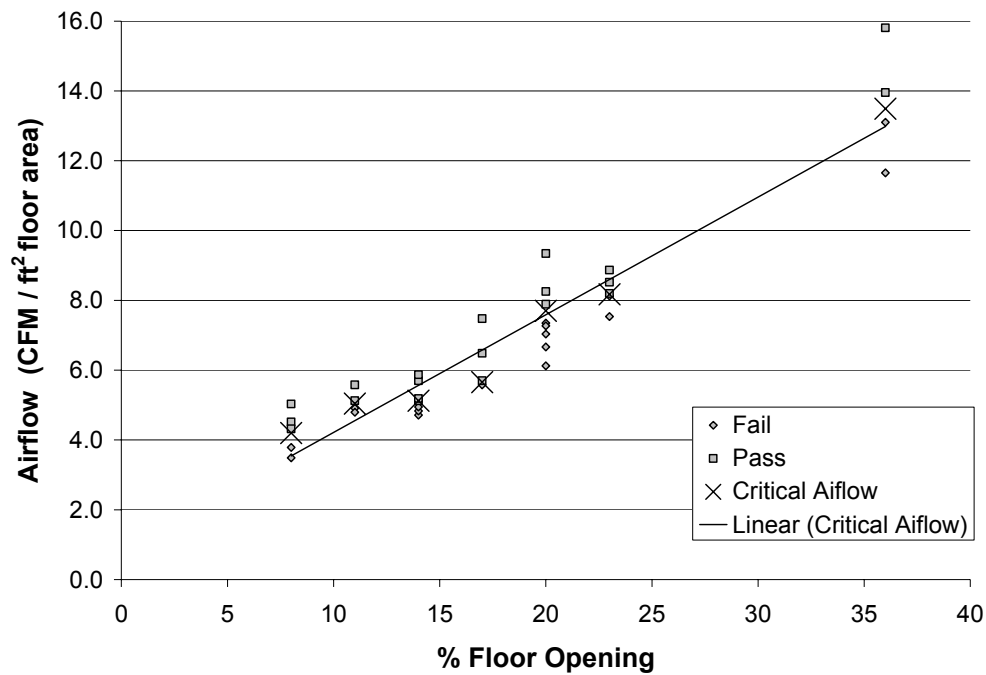

Figure 1. Critical airflow for various percent floor opening.

The critical airflow (Table 1 and X legend in Figure 1), for a given percent floor opening was interpolated between the minimum airflow that passed and the maximum airflow that failed, and was weighted according to visual observations of the from each trial. A linear regression ($R^2 = 0.95$) between critical ventilation rate per surface area of barn floor (cfm / ft^2)$_{critical}$ and percent floor opening (PFO) has the following relationship:

$$Cfm/ft^2_{critical} = 0.337 * PFO + 0.84 \qquad (1)$$

Table 1. Critical airflow and velocity.

% Floor Opening	Critical Airflow (cfm/ft² barn floor)	Critical Velocity (ft/min)
8	4.20	52.6
11	5.04	45.9
14	5.12	36.7
17	5.65	33.4
20	7.70	38.6
23	8.17	35.7
36	13.49	36.8

The data for all percent floor openings is normalized by determining the critical velocity through the barn slatted floor, i.e. critical airflow multiplied by the total open area in the slatted floor (Table 1). The critical velocity is expected to remain constant for all percent openings according to Bernoulli's equation on conservation of energy. Since the static pressure component of Bernoulli's equation is constant, the dynamic component would not change, i.e. velocity. The values ranged from 33.4 to 38.6 ft/min (mean of 36.2 ft/min), as expected, except for the 8 and 11 % floor openings, which are 52.6 and 45.9 ft/min respectively.

A finishing barn using 6-8 inch wide slats with 1 inch openings (11 to 14 % floor opening) requires 36 to 44 cfm per pig respectively (from eq 1) to assure down-drafting. The cfm/pig results are based on an occupancy density of 8 ft²/pig. The Hoff (1998) equation, (CFM/pig)$_{critical}$ = Percent Floor Opening * 1.92 – 1.92, for critical airflow suggests a ventilation rate of 19.2 to 25.0 cfm per pig. Compared to 36 to 44 cfm/pig for 11 to 14 % floor opening obtained in this study, the Hoff equation yields lower results. The differences between the two studies can be

explained by the visualization technique used to assess down-drafting. In the Hoff (1998) study, smoke sticks were placed just below the slatted floor system. In the present study, the smoke sticks were placed at 1 cm above the slatted floor. It is clear that the location for introducing visualization media affects the results. In this current study, with smoke sticks placed above the slatted floor, it makes sense that a higher pit-ventilation rate is required to prevent up-drafting as a result of the inlet system's influence on near-floor airflow pattern stability.

If the slatted floor is considered as an inlet to the pit head-space, and assuming the air flow is steady and at a constant density, there exists a pressure difference across the slats to prevent gases from up-drafting into the animal occupied zone. From Bernoulli's equation the pressure drop can be determined knowing the critical air velocity.

$$\Delta P = \frac{\rho}{2} \left(V_2^2 - V_1^2 \right)$$

(2)

where: ΔP = pressure drop, Pa

ρ = air density, kg/m^3

V_2 = air velocity through the slats, m/s

V_1 = air velocity in the pit head space, m/s

Applying mass conservation and assuming steady airflow through the slatted floor, Bernoulli's equation can be rewritten as:

$$\Delta P = \frac{\rho V_2^2}{2} \left[1 - \left(\frac{A_2}{A_1} \right)^2 \right]$$

(3)

where: A_2 / A_1 = the floor opening ratio

The expected pressure drop, calculated from the above formula, ranged from 0.02 to 0.04 Pa for 36 to 8 % floor opening respectively. Gustafsson (1987) found that a critical air flow rate was achieved with a pressure difference across the floor slats of 0.25 to 0.5 Pa. His critical velocity was defined as to prevent upward motion of air from the pit and to create even exhaustion over the floor surface. Gustafsson's study was performed in a barn with a partially slatted floor and a relatively shallow manure pit. The one order of magnitude difference may be explained by using a very environmentally controlled test chamber.

A minimum ventilation rate of 45 to 50 cfm per pig is recommended to achieve complete down-draft in a full slatted curtain sided swine finishing barn as the curtains are lowered. At these recommend rates the velocity through a 14 % floor opening slatted floor would be between 51 and 57 ft/min. These recommended velocities are higher than the critical velocity of 36.7 ft/min by a factor of 1.4 to 1.5. The factor chosen were to satisfy the purpose of this study, i.e. to determine the ventilation rate to maintain a positive pressure drop thus preventing up-drafting across totally slatted floors. Therefore a biofilter will treat all the pit gasses when the curtains are lowered.

The critical airflow required to achieve complete down-draft through slats exceeds current recommended minimum winter ventilation rates by a factor of four to five. During periods when the ventilation rate is less than the critical airflow, pit gasses may rise into the pig area but these gases do not leave the barn since the curtains are closed.

CONCLUSION

A visualization method was developed to measure the critical velocity through a swine slatted floor to maintain complete down-drafting.

Under ideal conditions the minimum pressure drop across the slats was calculated to be 0.02 to 0.04 Pa.

Complete pit gas odor reduction through a biofilter can be achieved both before and after the curtains are lowered by eliminating up-drafting after the curtains are opened. A recommended 45 to 50 cfm/pig ventilation rate through the pit head-space should be attained before the curtains are lowered. Setting the curtain controller set point for lowering in this ventilation rate range should eliminate up-drafting from the pit.

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