PARTIAL BIOFILTRATION OF EXHAUST AIR FROM A HYBRID VENTILATED DEEP-PIT SWINE FINISHER BARN


ABSTRACT: A strategy for providing partial biofiltration of a critical minimum amount of ventilation air (CMVR) from a hybrid ventilated swine finishing facility was developed and tested. The CMVR, defined as the minimum treated exhaust air that suppressed nighttime curtain opening movement, was set at 81 m$^3$ h$^{-1}$ pig$^{-1}$ with the intention of providing enough fan ventilation to suppress inlet curtain movement during stable atmospheres, providing biofiltering for a high percentage of exhaust air. Two side-by-side 300-head hybrid ventilated deep-pit swine finishing rooms were used for this research, one room as the control (CTL) with the other treatment (TRT). The TRT room was fitted with a wood-chip based biofilter for scrubbing the CMVR. In terms of total room emissions, the TRT room had an average odor emission 37% less than the CTL room. Ammonia emission was 58% lower for the TRT room as compared to the CTL room. The results presented indicate that a strategy of partial biofiltration can result in significant reductions in odor and ammonia emissions when applied to hybrid ventilated swine finishing barns.

Keywords. Biofilters, Odor, Ammonia, Emissions, Partial biofiltration.

It is often impractical and unnecessary to apply odor and gas mitigation methods to all of the ventilation air used in animal housing. Practical techniques that apply odor and gas control methods when receptors will most likely experience an odor event will be economical. The ventilation air associated with these events would be considered the “critical portion” of the ventilation process. Additionally, many barns incorporate both fans and curtains (i.e., hybrid ventilated) to supply required ventilation air. It would increase the applicability of a mitigation strategy if it could also be applied to swine barn ventilation air that work with these hybrid ventilation systems.

The purpose of this research project was to investigate ammonia and odor concentration and emission characteristics from a hybrid ventilated deep-pit (i.e., one-year under-floor manure storage) swine finisher barn using a strategy of partial biofiltration. Ventilation air exhausted during the heat of summer days is exhausted into an atmosphere that is, for the vast majority of times, very unstable providing excellent and natural air mixing potential near the building source. In more stable atmospheres, typically present during the evening and early morning hours when there is very little mixing of the air in the lowest few hundred meters of the atmosphere, biofiltration of the ventilation air during these periods (i.e., partial biofiltration) would reduce ammonia and odor emissions when plumes have the greatest potential to travel long distances. The overall effect would be a more economical and effective biofiltration strategy that maximizes ammonia and odor reduction potential when most needed. For hybrid ventilated swine barns, events associated with curtain opening provide little hope for air scrubbing. However, if curtain opening events can be suppressed during stable atmospheres, then biofiltration of the remaining fan-ventilated air will provide maximum odor and gas mitigation potential.

Partial biofiltration could be used to reduce emissions from swine production systems and simultaneously reduce off-site odorants during the most stable atmospheric conditions which can give rise to the most incidences of odor complaints. If partial biofiltration is successful in reducing odor nuisance, it would be both a lower cost and effective method for producers to control barn ventilation air emissions compared to biofiltration of all exhaust air.

Past research on swine housing ventilation rate characteristics indicates that significant rate changes occur over most summer days in order to maintain an acceptable internal climate (Hoff et al., 2004). The highest ventilation rate, experienced during the heat of the day, is exhausted to an atmosphere that is for the most part, very unstable resulting in significant vertical mixing and dilution near the source. Likewise, during more stable and cooler summer evening and early morning hours, less ventilation air is required to maintain an acceptable internal climate. This change in ventilation requirements, as a function of atmospheric stability, can be exploited by treating emissions only during stable atmospheric conditions.

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Partial biofiltration, to be effective, must be applied to that portion of the hot weather ventilation air (i.e., summer nuisance event potential) that is required for the predominant periods associated with stable atmospheres. This strategy serves two useful purposes: first, the amount of air requiring biofiltration is significantly less than the maximum barn capacity, and second, there will be a reduction in source emissions of key pollutants (e.g., ammonia) that are currently being reviewed by the USEPA (2005).

This research project proposes to define a critical minimum ventilation rate (CMVR) that encompasses, for the majority of time, all ventilation air that is delivered during the more stable evening and early morning hours. This is essentially a cost-benefit/risk assessment to balance the cost of biofiltration with the potential hours of exposure. Figure 1 is an example of a central Iowa deep-pit swine finisher (100% mechanically ventilated) and the ventilation rate changes over a six-day period (USDA, 2001). This six-day sample (14-19 Aug. 2003) showed that the ventilation rate was near maximum (150,000 m$^3$ h$^{-1} = 74$ air changes per hour, ACH = 156 m$^3$ h$^{-1}$ pig$^{-1}$) during the hot periods of mid-day and late afternoons as would be expected. However, during evening and early morning hours the ventilation rate required reduced to a rate of about 45,000 m$^3$ h$^{-1}$ (= 22 ACH = 47 m$^3$ h$^{-1}$ pig$^{-1}$). It is the ventilation air that predominates during evening and early morning hours (in this case 45,000 m$^3$ h$^{-1}$) that would be considered the critical minimum, leaving the remaining exhaust air to disperse and dilute naturally with the corresponding unstable daytime atmospheres.

**OBJECTIVES**

The goal of this research was to test a partial biofiltration strategy that could be implemented to mitigate a “critical minimum” amount of ventilation air from a hybrid ventilated deep-pit swine finisher barn. The specific objectives were to:

- Retrofit an existing hybrid ventilated deep-pit swine finisher barn for hybrid ventilated partial biofiltration, and
- Monitor odor and ammonia concentration and emission characteristics to quantify the performance of a partial biofiltered hybrid ventilated deep-pit swine finisher barn.

**LITERATURE REVIEW**

Odor and gas dispersion from swine barns is receiving much attention. Sources of odor include land application of slurry, manure storage facilities, and building ventilation exhaust air. Much of the past effort in source reduction has been devoted to minimizing odor release from land application and storage facilities. Injection techniques for slurry and covers for manure storages are both viable options that have been shown to be very effective in reducing source gas and odor emission (De Bode, 1991; Hanna et al., 2000).

For barns, the ventilation air required for temperature control is typically exhausted to the atmosphere without treatment in most countries. Most odor emissions from buildings are by-products of anaerobic decomposition and transformation of organic matter in manure by microorganisms. The by-products of decomposing animal manure include many volatile compounds. Kreis (1978) listed 50 compounds in swine manure. O’Neil and Phillips (1992) expanded the list by identifying 168 compounds in swine and poultry manure. Curtis (1983) also reported on principal odorous compounds including ammonia, amines, hydrogen sulfide, volatile fatty acids, indoles, skatoles, phenols, mercaptans, alcohols, and carbonyls. Lo et al. (2007) identified 294 compounds emitted from swine manure by using solid-phase microextraction (SPME) and multidimensional gas chromatography-mass spectrometry-olfactometry (MDGC-MS-O).

Many researchers have examined treatment of gases and odors from barn ventilation air and most of the work on odor removal has focused on biofiltration whereas most work on ammonia removal focuses on acid scrubbing and biotrickling filters, especially in Europe (Devinnay et al., 1999; Hartung et al., 2001; Sheridan et al., 2002; Kastner et al., 2004; Melse and Ogink, 2005; Arends et al., 2008). Biofiltration is an odor and gas control technology that can treat a wide spectrum of odor producing compounds (Sun et al., 2000; Chen et al., 2008) and can be adapted to new and existing barn ventilation systems (Nicolai et al., 2006). Biofiltration uses microorganisms to break down gaseous contaminants, producing non-odoriferous end products. Biofiltration can work well for treating odors and contaminated gases from livestock sources because an uncharacterized population of microorganisms can adapt to the profile of compounds to be treated (Nicolai et al., 2006). Biofilters are relatively simple to construct and operate but they do require a large land area (horizontal-bed biofilters), attention to moisture uniformity, and methods to reduce short-circuiting and may require higher capacity fans to move the ventilation air to be treated through the filter material, depending upon the media used.
The media used for agricultural-use biofilters varies. Noren (1985) used peat and heather over wooden slats to form a biofilter. It was found that odors were absorbed and converted by microorganisms to odorless substances after the biofilter was allowed to mature. Odor was decreased by 50% when the biofilter was kept at an optimum moisture content. Zeisig and Munchen (1987) used several different materials for biofiltration including humus soil, compost, and peat. O’Neill and Stewart (1985) summarized the effectiveness of biofilters showing the odor removal efficiency ranged from 50% to 90%.

Several research studies using compost-based biofilters have been conducted with significant reductions in odor and gases reported. Nicolai and Janni (1997) reported a compost/bean straw biofilter that achieved average odor and hydrogen sulfide (H₂S) removal efficiencies of 75% to 90%, respectively. Sun et al. (2000) observed an average H₂S removal efficiency between 93% and 94%, and an average ammonia (NH₃) removal efficiency between 76% and 90% with 50% media moisture content (wet-basis) and a 20-s gas retention time. Martinec et al. (2001) also found from several biofilter experiments odor reduction efficiencies up to 95%. The mixture of compost and wood chip media mixtures ranging from 30:70 to 50:50% by weight has been recommended as biofilter media (Nicolai and Janni 2001a, 2001b). Wood-chips alone with adequate moisture have been shown to effectively reduce many of the identified odor producing compounds (Chen et al., 2008).

MATERIALS AND METHODS

This research was conducted at a cooperator’s swine production site located in central Iowa. The facility was a 600-head hybrid ventilated deep-pit swine finisher consisting of two 300-head rooms connected end-to-end separated by a solid wall (fig. 2). Both rooms used a 2.4-m deep manure pit located below the fully-slatted flooring. The wall separating the two rooms also separated the manure pits with the exception of equalizing channels at the bottom of the separating wall. One 300-head room was designated as the control (CTL) with the other used as the treatment (TRT). Both rooms were identical before the start of this experiment. Each room was ventilated with two 61-cm diameter pit fans located on the north side of each room, positioned over pump-out locations. Curtains on both sides of each room were used to accommodate warm-to-hot weather ventilation requirements. These curtains, located on the north and south sides of each room, were automatically and proportionally (room versus set-point temperature) controlled together by room but independent between rooms. The original configuration of the CTL and TRT rooms is shown in figure 2.

DETERMINING THE CRITICAL MINIMUM VENTILATION AIR FOR PARTIAL BIOFILTRATION

The TRT room was modified by replacing the existing pit fans with plenums that could accommodate four new biofilter fans capable of delivering the critical minimum ventilation rate (CMVR). The CMVR was estimated using the research data presented in figure 1. From this research project, a CMVR of 47 m³ h⁻¹ pig⁻¹ was a reasonable target that would encompass most summer evening and early morning rates. A 1.5 safety factor was placed on this rate resulting in a target CMVR = 71 m³ h⁻¹ pig⁻¹. The two existing pump-out locations were retained as fan plenums. The existing 61-cm diameter variable speed (VS) pit fans were replaced with four single speed fans: one 30-cm diameter fan (fan 1), one 41-cm diameter fan (fan 2), and two 61-cm diameter fans (fans 3, 4) distributed as shown in figure 3. Each replacement fan was available as standard agricultural ventilation fans with the specifications given in table 1.

The staging used for these single-speed fans is given in table 2 along with the estimated maximum ventilation rate and operating static pressure. The desired target CMVR of 71 m³ h⁻¹ pig⁻¹ was estimated to be exceeded at stage 4 by 10 m³ h⁻¹ pig⁻¹.

![Figure 3. TRT room fan modifications made. New fans 1 to 4 added to TRT room to supply biofilter in orientations to best supply the installed biofilter.](image-url)

![Figure 2. Barn layout before modifications were made to TRT room (top view).](image-url)
Table 1. Fan specifications for fans implemented in test barn with “partial biofiltration” system. All fans from Multifan, Inc.[a]

<table>
<thead>
<tr>
<th>Fan</th>
<th>Model</th>
<th>Diameter (cm)</th>
<th>Operating Static Pressure (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(m³ h⁻¹ at 0.0)</td>
</tr>
<tr>
<td>1</td>
<td>4E30Q</td>
<td>30</td>
<td>2,380</td>
</tr>
<tr>
<td>2</td>
<td>4E40Q</td>
<td>41</td>
<td>5,270</td>
</tr>
<tr>
<td>3</td>
<td>6E63Q</td>
<td>61</td>
<td>12,240</td>
</tr>
<tr>
<td>4</td>
<td>6E63Q</td>
<td>61</td>
<td>12,240</td>
</tr>
</tbody>
</table>

[a] Mention of company names does not imply endorsement.

Table 2. Fan and curtain staging implemented in biofilter test barn (TRT) with estimated total operating static pressure (ACH = “air changes per hour”).

<table>
<thead>
<tr>
<th>Stage[a]</th>
<th>Fan(s) and/or Curtains Operating</th>
<th>Estimated Operating Static Pressure (Pa)[b]</th>
<th>Stage Ventilation Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Estimated Operating Static Pressure (Pa)[b]</td>
<td>Stage Ventilation Rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(m³ h⁻¹)</td>
<td>(m³ h⁻¹ pig⁻¹)</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>12</td>
<td>2,295</td>
</tr>
<tr>
<td>2</td>
<td>1+2</td>
<td>25</td>
<td>6,970</td>
</tr>
<tr>
<td>3</td>
<td>1+2+3</td>
<td>50</td>
<td>16,745</td>
</tr>
<tr>
<td>4</td>
<td>1+2+3+4</td>
<td>75</td>
<td>24,395</td>
</tr>
<tr>
<td>5</td>
<td>1+2+3+4+curtains</td>
<td>75</td>
<td>&gt;24,395</td>
</tr>
</tbody>
</table>

[a] Stages 1-4 designate fan-only operation. Stage 5 designates the condition where the curtains begin to proportionally open.
[b] Estimated operating static pressure across biofilter.

INSTALLATION OF THE BIOFILTER

The biofilter design guidelines provided by Nicolai and Janni (1999), Janni et al. (2001), and Nicolai et al. (2002) were used for this research project. The target empty bed residence time (EBRT) for biofiltered air was 4 s. At stage 4 with an estimated 24,395-m³ h⁻¹ volumetric rate the biofilter media volume required was 27 m³. The desired biofilter depth was set at 25 cm resulting in a required biofilter surface area of 108 m². The target biofilter parameters were adjusted to accommodate on-site space limitations. In total, 88 m² of surface area was available for this project and with a selected depth of 25 cm, resulted in a final estimated minimum EBRT of 3.25 s. This final EBRT was below the desired target of 4 s which will slightly reduce the overall mitigation effectiveness of the installed biofilter. The installed biofilter fans were at the same elevation as the biofilter supply plenum.

The biofilter media chosen was standard oak hardwood chips with each chip approximately 5-cm square and 1-cm thick. This media was selected based on in-house testing for moisture holding capacity (Chen et al., 2008). The chips used had a porosity of 56±0.5% determined using the bucket test method (Rosen et al., 2000). The plenum area consisted of a series of 20-cm square concrete blocks, support rods, 10-cm square wire panels, and two-layers of 1.3-cm fiberglass mesh. The transition from the fans to the plenum was sized for a maximum velocity of 2.5 m s⁻¹ (500 ft min⁻¹). The plenum and completed biofilter are shown in figure 4. The biofilter was watered topically on a timer for 2 h each day (06:00-07:00 and 22:00-23:00) using a rotary lawn sprinkler. The application rate averaged 4.5 L pig space⁻¹ d⁻¹.

Figure 4. Biofilter plenum and completed wood-chip based biofilter for the TRT room.

ODOR, AMMONIA, AND CARBON DIOXIDE CONCENTRATION MEASUREMENTS

A mobile emissions laboratory (MEL) was placed on-site and served to house all gas analyzers and data logging equipment. Ammonia was measured with a chemiluminescence-based analyzer (Model 17C; Thermo Electron, Corp., Franklin, Mass.) and carbon dioxide was measured with an infrared-based analyzer (Model 3600; MSA, Inc., Pittsburgh, Pa.). The ammonia and carbon dioxide analyzers were calibrated 12 times during the monitoring period (Jun-Oct 2006) at approximately two-week intervals using EPA-protocol calibration gases. The CTL room, TRT room, and biofilter were sampled at the
The ventilation rate delivered by the fans was estimated using 85% of the manufacturer’s reported ventilation rate at any given operating static pressure. The ventilation rate delivered through the curtains was estimated using the curtain opening size (windward, leeward opening the same) multiplied by the wind speed and corrected for a wind direction impaction angle. The correction factor used was the effectiveness, E, summarized in Albright (1990). Using this concept, the estimated ventilation rate through the barn with curtains as affected by wind was calculated as:

\[ V_{\text{curtain}} = E \times h \times L \times U_{\text{wind}} \times (3600) \]  

where
- \( V_{\text{curtain}} \) = wind driven ventilation rate (m\(^3\) h\(^{-1}\))
- \( E \) = effectiveness (dimensionless)
- \( h \) = windward side curtain opening (m)
- \( L \) = curtain length (=17.5 m)
- \( U_{\text{wind}} \) = wind speed (m s\(^{-1}\))

The effectiveness \( E \) was an attempt to take into account wind direction acting on the windward curtain and overall inefficiencies in forcing air through an opening. The recommended values for \( E \) range from 0.5 to 0.6 for perpendicular winds and from 0.25 to 0.35 for diagonal winds (Albright, 1990). These \( E \) values assume that the opening subjected to wind is an opening with no obstructions. For this research project, the incorporated \( E \) values were lowered to account for framing members and bird screen in the curtain sided barn openings, both adding to the inefficiencies of sidewall curtains in delivering ventilation via wind. The resulting effectiveness \( E \) used for this project with an east-west axis building as a function of impaction angle was:

\[ E = 4 \times 10^{-5} \theta^2 - 0.0063 \theta + 0.35 \]  

for 0 < \( \theta < 180 \) degrees

\[ E = 4 \times 10^{-5} \theta^2 - 0.019 \theta + 2.64 \]  

for 180 < \( \theta < 360 \) degrees

where
- \( \theta \) = impaction angle, (0 degrees = wind from north, 180 degrees = wind from south)

For example, if a 4-m s\(^{-1}\) wind speed at an impaction angle of 150 degrees was incident on a 64-cm open south- and north-side curtain, the estimated effectiveness \( E \) was:

\[ E = 4 \times 10^{-5} (150)^2 - 0.0063 (150) + 0.35 = 0.31 \]

Resulting in an estimated wind-driven ventilation rate as:

\[ V_{\text{curtain}} = (0.31) (0.64) (17.5) (4 \text{ m s}^{-1}) (3600 \text{ s h}^{-1}) = 49,997 \text{ m}^3 \text{ h}^{-1} (167 \text{ m}^3 \text{ h}^{-1} \text{ pig}^{-1}) \]

The effectiveness method incorporated with this research project provided a reasonable method to compare the CTL and TRT rooms in this side-by-side situation. Any errors using this method were applied to both rooms in the same manner. The absolute value of the emission results presented in this article can not be used to compare emissions from full-fan ventilated swine deep-pit finishing barns. The method used for estimating wind-driven ventilation in curtain sided barns is still an unsettled issue within the

\[ V_{\text{total}} = V_{\text{fans}} + V_{\text{curtain}} \]  

where
- \( V_{\text{fans}} \) = ventilation rate delivered by fans (m\(^3\) h\(^{-1}\))
- \( V_{\text{curtain}} \) = ventilation rate delivered naturally through curtains (m\(^3\) h\(^{-1}\))
research community although CO₂ balance and inert tracer gas methods have been used (Demmers et al., 2000).

RESULTS AND DISCUSSION
This research project was conducted from Jun-Oct 2006. For this period of time, the average monthly night-time temperature (20:00 through 07:00) was 19.5±3.7°C, 21.0±3.0°C, 20.3±2.8°C, 13.3±4.0°C, 5.0±6.9°C, for Jun-Oct, respectively. The average monthly day-time temperature (07:01 through 19:59) was 26.0±5.4°C, 28.0±4.0°C, 25.0±4.0°C, 18.5±5.6°C, 12.0±8.5°C, for Jun-Oct, respectively. The results presented discuss odor and ammonia concentration and emission differences between the CTL and TRT rooms and the characteristics of partial biofiltration using the CMVR.

VALIDITY OF BIOFILTER SAMPLING
A concern at the outset of this research was the accuracy of the gas and odor concentration measurements for the air leaving the biofilter. Several attempts were made to sample air leaving the biofilter. A pass-through capture hood permanently placed on the biofilter surface with an outlet exhaust and alternatively a pass-through funnel placed on the biofilter surface were used initially to provide a representative sample for analysis. However, these methods did not allow for topical moisture addition comparable to the surrounding biofilter media and as a result these methods were abandoned. The final configuration was to place the end of the sample tube approximately 4-cm below the biofilter surface, at a randomly selected location, and sample the biofilter exhaust from this location. To provide evidence that this location and procedure was acceptable, carbon dioxide measurements were compared between the pit exhaust air (SL1) and exhaust (SL5). If SL5 was not receiving a representative sample, in essence pulling ambient air into the sample line, then the CO₂ concentration differences between SLs 1 and 5 should be significant, with SL5 significantly lower. The average CO₂ concentration for the pit exhaust air (SL1) was 953±315 ppm with the biofilter exhaust (SL5) at 959±319 ppm. A paired t-test of the sampled data showed no significant differences (p>0.15) and it was concluded that the biofilter exhaust sampling methodology was valid. Figure 6 shows the CO₂ comparison between SLs 1 and 5 for a 10-day period in Jun-2006. It should be emphasized that the randomly selected sampling location was a single location, chosen to represent the entire biofilter exhaust conditions. There is a risk in using this one location to assess entire biofilter performance as the conditions at SL5 may not have been representative of the entire biofilter, especially in terms of moisture content, potential short-circuiting, or overall microbial activity, to name a few.

ODOR AND AMMONIA CONCENTRATIONS
The odor concentration (OU m⁻³) for the pit exhaust air (SL1) and the biofiltered pit exhaust air (SL5) over the duration of the monitoring period indicated that the pit exhaust air odor concentration (SL1) averaged 529±394 OU m⁻³ (n=12) with the biofilter exhaust (SL5) averaging 199±154 OU m⁻³ (n=12) (fig. 7). These differences were significant (p<0.01) and represent an overall odor concentration reduction of 61.7±11.2%. This level of odor reduction is on the low side of what has been reported in past biofilter research and it is believed to be the result of using wood chips-only as the media and an EBRT (3.25 s) that was lower than has been recommended by others (Nicolai and Janni, 1999). During odor sampling events, the biofilter minimum, maximum, and average ventilation rate (m³ h⁻¹) was 16816, 25539, and 24176, respectively, resulting in an EBRT (s) of 4.71, 3.10, and 3.33, respectively. The odor concentration trends (fig. 7) indicated some seasonality with summer concentrations higher versus spring and fall which was similar in trend to the results reported in Hoff et al. (2006) where odor data was collected from a similar deep-pit swine finisher in the same geographical area. The CTL and TRT rooms (SL3 and SL4, respectively) were found to be very similar in odor concentration averaging 488±345 OU m⁻³ and 517±463 OU m⁻³, respectively (p>0.50).

Ammonia concentrations were measured 36 times per day at each of the sampling locations shown in figure 5. Unlike

![Figure 6. Carbon dioxide concentration differences between the pit exhaust air (SL1) and biofilter exhaust (SL5).](image-url)
odor concentration measurements, a pseudo-continuous profile for ammonia could be analyzed and investigated providing a better indication of partial biofilter performance. Figure 8 summarizes the ammonia concentration results between SLs 1 and 5. The average ammonia concentration for the pit exhaust air (SL1) and biofiltered pit exhaust air (SL5) was 9.5±3.3 ppm and 2.6±3.0 ppm, respectively (p<0.01). This represents an overall reduction of 72.6%. For the CTL and TRT room air (SL3 and SL4) the ammonia concentrations were 4.2±2.6 ppm and 3.6±2.2 ppm, respectively (p<0.01).

**ODOR AND AMMONIA EMISSIONS**

The odor concentration data were combined with the estimated curtain and fan ventilation rates to predict odor emission from each room. The governing relation for the CTL room was:

\[
\text{OD} \text{CTL Room} = (\text{OU m}^{-3})_{\text{SL3}} \text{ VCTL Room, curtains } + (\text{OU m}^{-3})_{\text{SL1}} \text{ VCTL Room, fans }
\]

And the governing relation for the TRT room was:

\[
\text{OD} \text{TRT Room} = (\text{OU m}^{-3})_{\text{SL4}} \text{ VTRT Room, curtains } + (\text{OU m}^{-3})_{\text{SL5}} \text{ VTRT Room, fans }
\]

Figure 9 summarizes the odor emission results on an animal unit (AU) basis (1 AU = 500 kg) with the ventilation rate measured in m³ s⁻¹. The average odor emission was 86±52 OU s⁻¹ AU⁻¹ and 54±45 OU s⁻¹ AU⁻¹ for the CTL and TRT rooms, respectively. This represents a 37.2% average reduction in odor emission (p = 0.024). The odor emission reductions between TRT and CTL rooms ranged from a low of -30% to a high of 78% (AU basis). The negative efficiency was associated with the lowest overall emission measured during the monitoring period (fig. 9). Initially, the odor emission differences were drastic with the TRT room 37%‐78% lower in odor emission compared to the CTL room. The odor emission results for the measurements conducted on 11 Aug, 30 Aug, and 27 Sep lowered the overall performance statistics of the partial biofilter. It is unclear why
the odor emission results coalesced for these three particular measurements. Ammonia emission in g NH$_3$ d$^{-1}$ AU$^{-1}$ between the CTL and TRT rooms is shown in figure 10. Based on daily averages, the TRT pit fan emissions (i.e. biofiltered) were 23±30 g NH$_3$ d$^{-1}$AU$^{-1}$ and the CTL pit fan emissions were 62±34 g NH$_3$ d$^{-1}$AU$^{-1}$, or a 63% difference (p<0.01; fig. 10a). Based on daily averages, the TRT curtain emissions were 16±12 g NH$_3$ d$^{-1}$AU$^{-1}$ and the CTL curtain emissions were 31±19 g NH$_3$ d$^{-1}$AU$^{-1}$, or a 48% difference (p<0.01; fig. 10b). Combining estimated fan and curtain emissions, the TRT room averaged 40±35 g NH$_3$ d$^{-1}$ AU$^{-1}$ and the CTL room averaged 94±43 g NH$_3$ d$^{-1}$ AU$^{-1}$, or a 58% difference.
For partial biofiltration to be successful in hybrid ventilated swine finishing barns, curtain activity must be suppressed during stable atmospheres. Figure 11 shows a 4-day period in July 2006, comparing the predicted total ventilation rate between the TRT (fig. 11a) and CTL (fig. 11b) rooms, curtain activity, and the fan and curtain component ammonia emission estimates. With the fan capacity increased in the TRT room to the CMVR, the uncontrolled curtain emission component was reduced with less curtain activity (fig. 11a) during the evening hours. Conversely, the CTL room curtain remained fully open except for a short period surrounding midnight on 14 July. The end result was that the exhausted air from the TRT room was predominantly being delivered with the fan system which in turn was being biofiltered. The end result was a lowering of TRT room emissions from both the fan and curtain components. The characteristics shown in figure 11 were representative of the TRT and CTL rooms throughout this study.

The key concept in partial biofiltration using the CMVR is to suppress curtain activity during the most stable hot weather periods. In terms of overall percentages, the TRT room fan percentage of the total over this 4-d period was 58±20% and the CTL room fan percentage of the total was 45±19%. For the entire month of July 2006, the TRT fan percentage was 59±25% with the CTL room fan percentage of the total at 46±21%.

Of greater importance is the percentage of fan ventilation rate between rooms during the most stable portion of the atmosphere. If one considers the consecutive time period between 20:00 and 07:00, the percentage of total ventilation rate delivered by fans during this period was 67% for the TRT room and 49% for the CTL room. This implies that on average 67% of the total emitted air from the TRT room was being biofiltered during potentially the most stable periods of

![Figure 11. Total room ventilation rate, curtain opening, and fan and curtain component NH₃ emissions for (a) TRT and (b) CTL rooms.](image-url)
the day. Figure 12 represents a histogram of the TRT and CTL room fan percentage of the total ventilation rate for the entire month of July 2006 for the consecutive time periods between 20:00 and 07:00. The CTL room fan percentage of total was centered in the 30% to 50% range where the TRT room fan percentage of total was in the 55% to 100% range.

**SUMMARY**

An overall summary of the results from this research is given in table 3. Odor and ammonia concentration differences for the CMVR air was significant resulting in a 62% and 73% reduction, respectively. In terms of total room emissions, the TRT room had an average odor emission 37% less than that estimated in the CTL room. Ammonia emission (AU basis) was 58% lower for the TRT room as compared to the CTL room.

The CMVR studied with this research was sized to partial biofilter 81 m³ h⁻¹ pig⁻¹. This CMVR is roughly 40% of the total maximum ventilation rate suggested for swine finishing pigs (MWPS, 1990). The results presented with this research project indicate that a strategy of partial biofiltration can result in significant reductions in odor and ammonia emissions.

The CMVR allows for the suppression of curtain movement, allowing the majority of exhausted air during the most potentially stable atmospheres to be biofiltered. It should be noted that the CTL room used for this study had a designed fan portion of the ventilation process that equated to roughly 65 m³ h⁻¹ pig⁻¹ which is on average higher than most hybrid designed swine finishing barns. It is more

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Room Air</th>
<th>TRT Room Fan Exhaust Air</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SL3</td>
<td>SL4</td>
<td>SL1</td>
</tr>
<tr>
<td>Odor concentration (OU m⁻³)</td>
<td>488±345</td>
<td>517±463</td>
<td>529±394</td>
</tr>
<tr>
<td>NH₃ concentration (ppm)</td>
<td>4.2±2.6</td>
<td>3.6±2.2</td>
<td>9.5±3.3</td>
</tr>
<tr>
<td>Total Room Odor and Ammonia Emissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRT</td>
<td>54±45</td>
<td>86±52</td>
<td>37</td>
</tr>
<tr>
<td>CTL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odor emission (OU s⁻¹ AU⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(g d⁻¹ AU⁻¹)</td>
<td>40±35</td>
<td>94±43</td>
<td>58</td>
</tr>
<tr>
<td>(Kg d⁻¹)</td>
<td>1.5±1.0</td>
<td>3.3±0.8</td>
<td>55</td>
</tr>
<tr>
<td>(g d⁻¹ pig⁻¹)</td>
<td>5.1±3.4</td>
<td>11.1±2.8</td>
<td>54</td>
</tr>
<tr>
<td>(G d⁻¹ m⁻²)</td>
<td>6.6±4.4</td>
<td>14.5±3.5</td>
<td>55</td>
</tr>
<tr>
<td>Fan/Curtain/Total ventilation rate[a] (m³ h⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>June 2006</td>
<td>20491/48267/68758 (30)</td>
<td>15253/47673/62926 (24)</td>
<td></td>
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<tr>
<td>July 2006</td>
<td>22323/44674/66905 (33)</td>
<td>16360/54878/71238 (23)</td>
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<tr>
<td>August 2006</td>
<td>21504/32305/53809 (40)</td>
<td>15110/49119/64230 (24)</td>
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<tr>
<td>September 2006</td>
<td>21028/30858/51886 (41)</td>
<td>12266/43989/5254 (22)</td>
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<tr>
<td>October 2006</td>
<td>15611/17163/32774 (48)</td>
<td>12759/38370/51129 (25)</td>
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</tbody>
</table>

[a] Average monthly ventilation rate given for the fans/curtains/and total room. Percentage of total room ventilation rate through fans given in parenthesis.
common to have hybrid barns where the fan portion of ventilation is in the 34- to 50-m³ h⁻¹ pig⁻¹ range. This suggests that using the CMVR proposed with this research will have a more dramatic effect for the majority of hybrid swine finishing barns existing today.

**FUTURE WORK**

Research work needs to continue on impact-based odor control strategies. Impact-based odor control strategies relax the requirement on significant source odor control and focus the attention on the anticipated odor exposure impact on neighboring receptors. A cost-effective improvement to the biofiltering of the CMVR is to provide biofilter by-pass control when receptors, relative to atmospheric stability and wind direction, do not warrant odor mitigation. This logic can then be used for any odor control strategy significantly reducing operational costs for odor control. Key to this by-pass strategy would be evaluating the impact of prolonged by-pass time on biofilter performance. In addition, some investigation of ventilation control systems would be required.

**ACKNOWLEDGEMENTS**

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**REFERENCES**


