

Practical Partial Biofiltration of Swine Exhaust Ventilation Air

S. Hoff¹, J. Harmon¹, L. Chen¹, K. Janni², D. Schmidt², R. Nicolai³, and L. Jacobson²
Iowa State University¹, University of Minnesota², South Dakota State University³

Species: Swine
Use Area: Animal Housing
Technology Category: Biofilter
Air Mitigated Pollutants: Ammonia (NH₃), Odor

Description:

The mitigation technique discussed is to utilize biofiltration for a portion of swine barn ventilation air. The portion mitigated is that portion of air emitted into stable atmospheres. Stable atmospheres have poor vertical mixing potential and therefore gases and odors emitted tend to remain close to the earth's surface and can therefore be sensed at longer distances downwind. It is impractical to mitigate all of the exhaust ventilation air required in swine housing. Techniques are needed that apply odor and gas mitigation to a portion of the ventilation air stream, when receptors might experience an odor event. Additionally, many barns incorporate combinations of fans and curtains (i.e. hybrid ventilated) to supply required ventilation air. Any mitigation strategy applied to barn ventilation air must be able to accommodate these hybrid ventilation systems as well.

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 mixing potential near the building source. In more stable atmospheres, typically present during the evening hours, biofiltration of a critical minimum amount of ventilation air (i.e. partial biofiltration) would reduce ammonia and odor emissions during those times when the potential for odor plumes to travel long distances is greatest. The overall effect would be a more attractive biofiltration strategy that maximizes ammonia and odor reduction potential when most needed.

A strategy for providing partial biofiltration of a critical minimum amount of ventilation air for hybrid ventilated swine finishing facilities was developed and tested. The biofiltered critical minimum ventilation air (CMVR) was set at 81 m³/h pig (48 ft³/min-pig) with the intention of providing enough fan ventilation in a hybrid ventilated swine finishing facility to suppress curtain movement during stable atmospheres. 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 and an average ammonia emission 58% less than the CTL room.

Mitigation Mechanism:

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 maximum ventilation rates experienced during the heat of the day are 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 hours, a lesser amount of ventilation air is required to maintain an acceptable internal climate. This change in ventilation requirements, as a function of atmospheric stability, can be used to enhance the usefulness of odor and gas mitigation for barn ventilation air.

Partial biofiltration, to be effective, must be applied to that portion of the ventilation air that is required for the predominant periods associated with hot weather evenings. This "critical minimum" amount of ventilation air mitigated would treat exhausted air when the potential for off-site gas and odor transport is greatest. This strategy will serve two useful purposes; first, the amount of air required for biofiltration will be significantly less than the maximum barn capacity, and second, the end result will be a reduction in source emissions of key pollutants that are currently being reviewed by the USEPA (2005).

This research defines a critical minimum ventilation rate (CMVR) that encompasses, for the majority of time, ventilation air that is delivered during the more stable evening hot-weather hours. Figure 1 is an example of a central Iowa deep-pit swine finisher and the ventilation rate changes over a six-day period (USDA, 2001). This six-day sample (Aug 14-19, 2003) shows that the ventilation rate was near maximum (140,000 m³/h = 146 m³/h-pig = 86 ft³/min-pig) during the hot periods of mid-day as would be expected. However, during early evening, evening, and early morning hours the ventilation rate required reduced to a rate of about 50,000 m³/h (= 52 m³/h-pig = 31 ft³/min-pig). It is the ventilation air

that predominates during hot-weather evening hours that would be considered the critical minimum, leaving the remaining exhaust air to disperse and dilute naturally with the corresponding unstable day-time atmospheres.

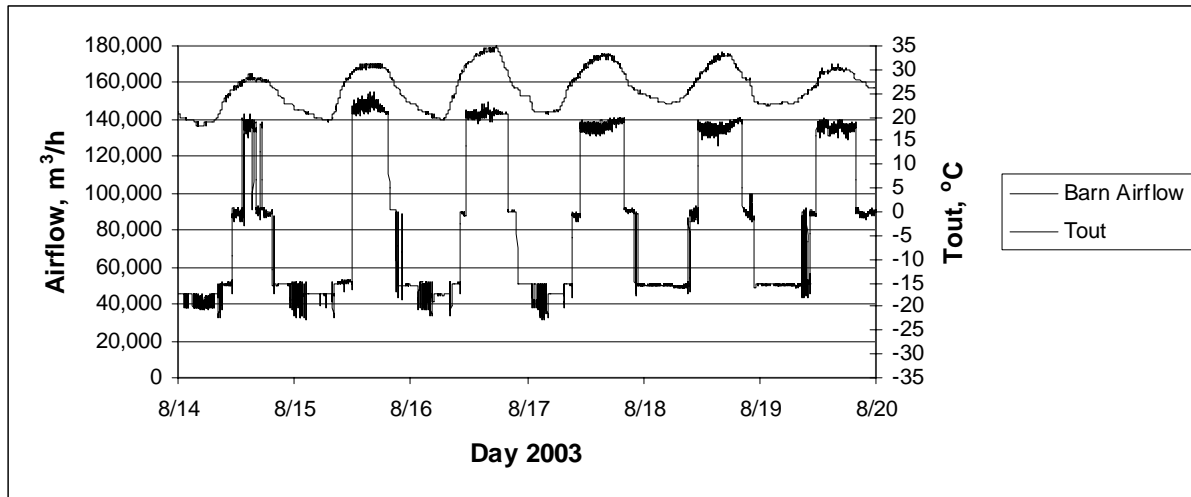


Figure 1. Building airflow changes with summer outside temperature.

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 hybrid ventilated deep-pit swine finishers. Mitigation performance and operating costs are presented in this paper. Highlights of this research are discussed in this paper. A more detailed description can be found in Hoff et al. (2008).

Applicability:

The strategy of partial biofiltration presented in this paper was developed for hybrid ventilated swine finishing facilities. The concept of partial mitigation, beyond biofiltration, can be implemented to other gas and odor mitigation technologies involving animal housing ventilation air. Partial treatment of ventilation air is in general an “impact-based” technology where mitigation is applied to exhausted air that has the potential for impacting neighboring residences.

Limitations:

Treatment of exhaust ventilation air from animal housing must not negatively affect animal performance with ventilation rate restrictions. It is important that fan capacity be sized appropriately to accommodate biofilter requirements while maintaining the integrity of the ventilation system required for the housed animals. The project presented here investigated the use of biofilters on hybrid-ventilated deep-pit swine finishing facilities. Implementation of partial biofiltration on alternative ventilation methods (ie. tunnel ventilated) was not conducted with this research.

Proper performance of biofilters requires an ample water supply to keep the biofilter media in the 50-60% range to be as effective as possible (Nicolai et al., 2006; Chen et al., 2008). In addition, one often over-looked situation that can exist in deep-pit swine finishing facilities is the fact that as manure level rises, there is a tendency for pit-fan intake blockage due to physical constraints between the slatted floor level and support beams required for the flooring. It is not uncommon to have pit fan intakes completely blocked with a full or near-full pit. In this situation, any mitigation strategy applied to pit fans is rendered useless.

Cost:

The biofilter application presented in this research required \$4,959 for biofilter supplies and equipment including four new biofilter fans (table 1). The biofilter construction required approximately 120 hours of labor and at \$15/hour equates to \$1,800. In total, with supplies, equipment, and labor, the construction costs equaled \$6,759 or \$22.53/pig space. The biofilter fan operating costs averaged \$0.0084/day-space to operate (June-October 2006 data used) compared to the control barn of \$0.0034/day-space. This extra fan cost, spread over the pigs produced in one year, equates to an additional \$0.42/pig-produced in biofilter fan operational costs.

Table 1. Biofilter construction costs.

Item	\$/Unit	Unit	Units/f t ²	\$/ft ²	Total*	\$/pig- space	Life, yrs	Pigs/Life	\$/pig
Concrete block	\$0.94	each block	0.50	\$0.47	\$445	\$1.48	30	22,500	\$0.02
Support bars	\$0.33	ft (3/4 inch diameter)	1.00	\$0.33	\$313	\$1.04	15	11,250	\$0.03
Hog panel	\$0.38	ft ²	1.00	\$0.38	\$355	\$1.18	15	11,250	\$0.03
Fiberglass mesh	\$0.67	ft ²	1.00	\$0.67	\$634	\$2.11	10	7,500	\$0.08
Replacement fans	\$1,800	15,000 ft ³ /min	1.00	\$2.00	\$1,894	\$6.31	15	11,250	\$0.17
Plywood border/plenum	\$20.00	4 ft x 8 ft sheet	0.01	\$0.20	\$189	\$0.63	7	5,250	\$0.04
Wood chips	\$1.43	ft ³	0.83	\$1.19	\$1,129	\$3.76	3	2,250	\$0.50
Total less labor					\$4,959	\$16.53			\$0.87
Total less fans and labor					\$3,065	\$10.22			\$0.70

* for the 947 ft² biofilter constructed.

Implementation:

This research was conducted at a cooperator's swine production site located in central Iowa. The facility used was a 600-head hybrid ventilated deep-pit swine finisher consisting of two 300-head rooms separated by a solid wall. Both rooms used a 2.4 m (8 ft) deep manure holding tank located below the fully-slatted flooring. The wall separating the two rooms also separated the manure holding tanks 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 (24 in) diameter pit fans located on the north side of each room, placed 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 controlled together by room but independent between rooms. The CTL and TRT configuration with the biofilter applied to the TRT room is shown in figure 2.

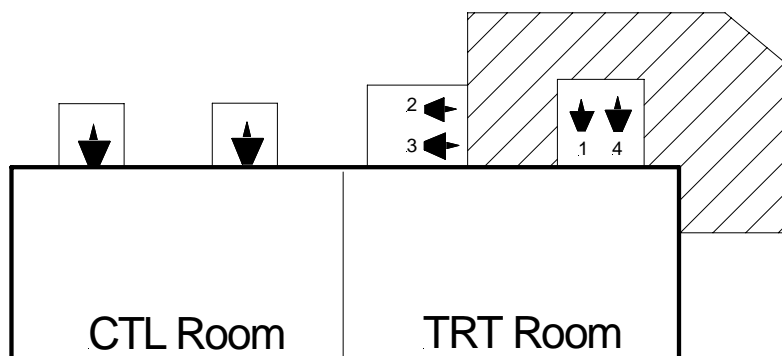


Figure 2. Biofilter layout with gas sampling locations.

The two original TRT room variable speed pit fans were replaced with four single-speed fans, controlled in four stages (table 2). Each of the four fans was progressively activated with each stage. At the final stage 4 condition, and assuming an operating static pressure of 75 Pa (0.30 in water column), results in an estimated maximum volumetric rate through the biofilter of 24,395 m³/h (14,347 ft³/min).

Table 2. Biofilter fan specifications and staging. All fans from Multifan, Inc.

Fan ID*	Model	Diameter, cm	Operating Static Pressure, Pa		
			0.0	12.5	75.0
1	4E30Q	30	2,380	2,295	1,615
2	4E40Q	41	5,270	5,015	3,400
3	6E63Q	61	12,240	11,730	9,690
4	6E63Q	61	12,240	11,730	9,690

*see figure 2

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 residence time for biofiltered air was 4 sec. At stage 4 with an estimated 24,395 m³/h (14,347 ft³/min) delivery rate, the biofilter volume required to achieve a 4 sec retention time was 27 m³ (953 ft³). The desired biofilter depth was established at 25 cm (10 in) resulting in a required biofilter surface area of

108 m² (1,162 ft²). The target biofilter parameters were adjusted to accommodate on-site space limitations. In total, 88 m² (947 ft²) of surface area was available for this project and with a selected depth of 25 cm (10 in), resulted in a final minimum residence time of 3.25 sec.

The biofilter media chosen was standard oak hardwood chips with each chip approximately 5 cm square (2 in). This media, free of fines, was purchased from a local supplier of landscaping products. This media was selected based on in-house testing for moisture holding capacity (see 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 biofilter plenum consisted of a series of 20 cm (8 in) square concrete blocks, electrical conduit used as support rods, 10 cm square (4 in) wire panels, and two-layers of 1.3 cm (0.5 in) fiberglass mesh. The plenum and completed biofilter is shown in figure 3. The biofilter was watered on a timer for two hours each day (06:00-07:00 and 22:00-23:00). The application rate averaged 4.5 liters/day-pig (1.2 gal/day-pig).

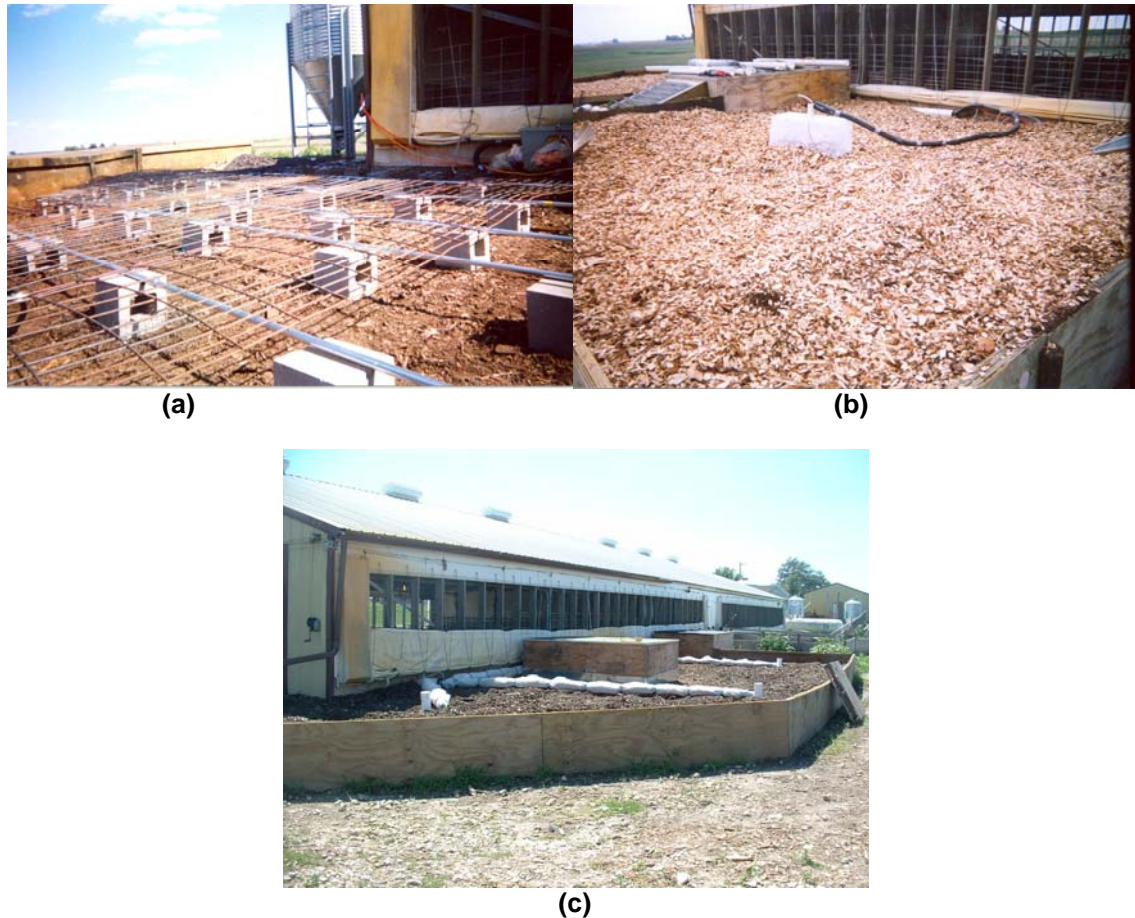


Figure 3. Biofilter plenum (a), wood chip media (b), and completed biofilter (c).

The key concept in partial biofiltration using the CMVR is to suppress curtain activity during the most stable hot weather periods and to transfer the ventilation needs to the biofilter fans. From this research project, the fan percentage of the total airflow rate delivery was recorded between the CTL and TRT rooms. Considering the consecutive time period between 20:00 and 07:00, the percentage of total airflow delivered by fans during this time 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 the day. Figure 4 shows a histogram of the TRT and CTL room fan percentage of the total airflow 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 30-50% range where the TRT room fan percentage of total was in the 55-100% range.

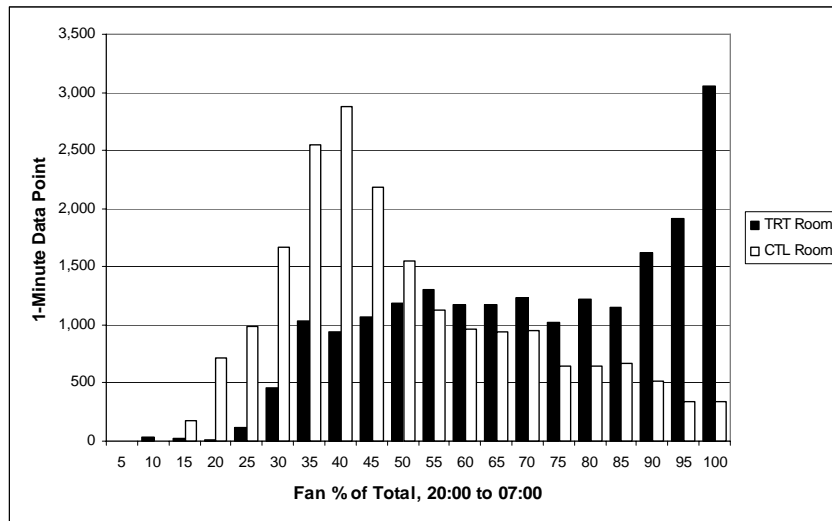


Figure 4. Percent of total room airflow delivered by fans between the CTL and TRT rooms.

Based on the experiences from this research project, some highlighted areas are noted below;

Biofilter Media: Very careful attention to biofilter media composition needs to occur. The media selected must be screened for fines. If compost is mixed with wood chips, the fraction of compost needs to adhere strictly to the recommendations given in past documents on biofilter design (Nicolai and Janni, 2001). This research project showed that a biofilter consisting strictly of wood chips is an effective media for biofiltration provided adequate moisture is applied and retained.

Biofilter Plenum Design: It has been a common practice to use stacked wood-pallets for constructing horizontal-bed biofilter plenums. A modified approach using concrete blocks, galvanized support bars, hog panel, and mesh proved to work well. Caution in the selection of mesh material needs to be considered. Two-layers of fiberglass mesh (1.3 cm square) were used and after two years of operation it has been observed that wood-chip fines have settled causing significant airflow obstruction. The mesh used should be just small enough to prevent the original wood chip material from passing into the plenum.

Biofilter Fan Transition: It is extremely important that the transition area from the fan to the biofilter plenum be designed in such a manner that an easy and restriction-free zone exists into the biofilter. The transition area that was designed for this research project used a velocity criterion of $9,150 \text{ m}^3/\text{h}\cdot\text{m}^2$ ($500 \text{ ft}^3/\text{min}\cdot\text{ft}^2$). The recommendation would be to maintain this transition area at or below this level for all locations prior to the biofilter plenum. Failure to provide adequate distribution area into the biofilter plenum will result in excessive operating static pressures.

Partial Biofiltration: The results from this research support the concept of partial biofiltration. The research data collected for this project demonstrated that a significant portion of the evening hours was fan ventilated and scrubbed *via* biofiltration at a maximum biofilter fan rate of $81 \text{ m}^3/\text{h}\cdot\text{pig}$ ($48 \text{ ft}^3/\text{min}\cdot\text{pig}$). This rate is roughly 50% of the total fan capacity designed in swine finishing facilities.

Barn Modifications: It is important that secondary inlets into the attic space and primary inlets into the occupied room space be sized to design specifications to avoid excessive operating static pressure. With the added restriction of a biofilter, the ventilation system needs to minimize all other air restriction points in the ventilation process beyond the inlet distribution system itself. Ultimately, the biofilter installed can not negatively affect the ventilation needs of the animals

Technology Summary:

The technology summarized in this paper used a biofilter to treat a critical minimum amount of ventilation air in a hybrid-ventilated deep-pit swine finisher. The logic of the method described is to provide just enough ventilation air mitigation to suppress curtain opening during predominantly stable summer night-time conditions when the tendency for odor transport is greatest. The method discussed and tested had an estimated capital and labor cost of \$22.53/pig-space and an added biofilter fan operational cost of \$0.42/pig.

Additional Resources:

More specific details related to the research project summarized in this paper can be found in Hoff et al. (2008). Biofilter design considerations can be found in Nicolai and Janni (1999), Janni et al. (2001), and Nicolai et al. (2002).

Acknowledgments:

The authors would like to thank Mr. Greg Carlson, Stratford Iowa, for allowing this research project to be conducted at his production site. The support staff consisting of Brian Zelle, Michael Crevalt, David Smith, and Aaron Smith spent many hours working through design changes and site inspections required to make this research project possible and their support is very much appreciated. The authors would like to thank the Iowa Pork Producers Association and the USDA-Special Grants program for making this research project possible with their generous funding support.

References:

- Chen, L., S.J. Hoff, J.A. Koziel, L. Cai, B.C. Zelle, and G. Sun. 2008. *Performance Evaluation of a Wood Chip-Based Biofilter Using Solid-phase Microextraction and Gas Chromatography-Mass Spectrometry-Olfactometry*. Bioresource Technology (in press).
- Hoff, S.J., D.S. Bundy, M.A. Huebner, B.C. Zelle, L. D. Jacobson, B.P. Hetchler, V.J. Johnson, R.E. Nicolai, D.R. Schmidt, P.R. Goodrich, A.J. Heber, J.Q. Ni, T.T. Lim, P.C. Tao, Y.Zhang, J. McClure, S. Jerez, M. Roberts, J.A. Koziel, B.H. Baek, A. Balota, J.P. Spinhirne, J.M. Sweeten, D.B. Beasley, G.R. Baughman, R. Munilla. 2004. *Real-Time Ventilation Measurements from Mechanically Ventilated Livestock Buildings for Emission Rate Estimations*. ASAE Meeting Paper No. 04-4178. St. Joseph, Mich.: ASAE.
- Hoff, S.J., J.D. Harmon, L. Chen, K.A. Janni, D.R. Schmidt, R.E. Nicolai, and L.D. Jacobson. 2008. *Partial biofiltration of a hybrid ventilated deep-pit swine finisher*. Applied Engineering in Agriculture (in-review).
- Janni, K.A., W.J. Maier, T.H. Kuehn, C.H. Yang, B.B. Bridges, and D. Vesley. 2001. *Evaluation of biofiltration of air, an innovative air pollution control technology*. ASHRAE Transactions, Vol 107, Part 1. pp. 198-214.
- Nicolai, R. E., and K. A. Janni. 1999. *Effect of biofilter retention time on emissions from dairy, swine, and poultry buildings*. ASAE Paper No. 994149. St. Joseph, Mich.: ASAE.
- Nicolai, R. E., Janni, K. A., 2001. *Determining pressure drop through compost-wood chip biofilter media*. ASAE Paper No. 014080. St. Joseph, Mich.: ASAE.
- Nicolai, R.E., Janni, K.A. and D.R. Schmidt. 2002. Biofilter design information. <http://www.bae.umn.edu/extens/aeu/baeu18.html>
- Nicolai, R.E., C.J. Clanton, K.A. Janni, and G.L. Malzer. 2006. *Ammonia removal during biofiltration as affected by inlet air temperature and media moisture content*. Transactions of the ASABE, 49(4): 1125-1138.
- Rosen, C.J., T.R. Halbach, and R. Mugaas. 2000. *Composting and mulching, A guide to managing organic yard wastes*. University of Minnesota Extension Service, BU-3296-F, p.2.
- USDA. 2001. USDA-IFAFS Project "Aerial Pollutant Emissions from Confinement Animal Buildings (APECAB)". Six state integrated research project between Minnesota, Indiana, Iowa, Illinois, North Carolina, and Texas. 09/2001 to 09/2005.
- USEPA. 2005. Environmental Protection Agency, Animal Feeding Operations Consent Agreement and Final Order. Federal Register Vol. 70, No. 19 / Monday, January 31, 2005.

Point of Contact:

Steven J. Hoff, Ph.D.
Iowa State University
212 Davidson Hall
Ames, IA 50011
USA
515-294-6180
hoffer@iastate.edu

As published in the proceedings of:
**MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING
OPERATIONS CONFERENCE**
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
Sponsored by:
NRI Air Quality Extension & Education
Iowa Farm Bureau Federation
Iowa Egg Council
Iowa Pork Industry Center
Iowa Pork Producers Association
U.S. Pork Center of Excellence