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Impact Based Odor Control System

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Abstract. *Biofilters are an effective and economically feasible technique for mitigating odor and other gaseous emissions from livestock production systems. They consist of a media containing a biofilm, where microorganisms break down compounds in livestock building exhaust air into energy and nutrients for growth and reproduction. In addition to capital costs, continuous filtering of exhaust air from mechanically ventilated buildings can be expensive and not always required, if odor is considered nuisance; thus, an automated control system was designed to filter odorous air when surrounding neighbors are most likely to be impacted and bypass the biofilter when odor impact potential is low. This ON/OFF control strategy can reduce energy usage by operating exhaust fans more efficiently at lower static pressures, when no filtering is required. The Impact Based Odor Control System (IBOCS) monitors wind speed and direction, dry-bulb temperature, relative humidity, and insolation to assess atmospheric stability and utilizes the location of neighbors relative to a facility to determine if exhaust air requires filtering. An Arduino stored in a weatherproof housing served as the main control by recording sensor measurements, neighbor locations, storing data on a flash card, and activating louvers to bypass or filter the exhaust air. The user interface consisted of an eight-direction toggle switch indicator (relative neighbor location), on/off switch, automatic/manual switch to override IBOCS, and open/close buttons for use in manual operation. IBOCS was field tested for two years at a commercial swine finishing facility in central Iowa with encouraging results for reducing biofilter operational time. The overall goal of IBOCS is to reduce odor impact to nearby receptors via removing odor from the exhaust air and concurrently decrease operational expenses of the mitigation technology.*

Keywords. *swine, odor abatement, ventilation, biofilter, building*

Introduction

In the swine industry, odor dispersion has experienced scrutiny from rural communities and regulators. Swine odors produced from the breakdown of manure by microorganisms are emitted from land application of slurry, manure storage, and building ventilation exhaust air (Liu, Powers, & Mukhtar, 2014). Typically, exhaust air from swine facilities is untreated, allowing odors containing hundreds of chemicals, including volatile organic compounds, ammonia, hydrogen sulfide, and many other substances found at low concentrations (Zhang et al., 2002), to be detected by the human olfactory response. Further, legislation is becoming increasingly strict on odor and gaseous emissions levels (Honeyman, 1996; Liu et al., 2014; Vukina, Roka, & Palmquist, 1996). There is a requisite need for developing and implementing odor mitigation technologies that are cost effective and reduce impact on surrounding communities.

If odor is regarded solely as a nuisance, and not an environmental hazard, such that the objective of treating exhaust air is to positively affect nearby neighbors, it is often unnecessary to treat all exhaust air, all of the time. Odors may not be detected by nearby receptors due to weather, number of animals present, or relative location and distance from the facility; hence, operating time of a mitigation strategy is reduced by treating exhaust air only when a receptor may detect dispersed odor. This approach maximizes odor reduction potential when most needed, with economic benefit and enhanced effectiveness. The capability to automatically bypass a mitigation technology will decrease energy to operate the filtration device and fan(s).

Several methods have been developed to mitigate odors from the exhaust air such as biofilters, wet scrubbers, oil spraying, ultraviolet light, and electrostatic precipitation ("Air Management Practices Assessment Tool (AMPAT)," 2015; Liu et al., 2014). Biofilters are a promising economically feasible technology that reduces both a wide range of odor producing compounds and gaseous emissions. They consist of a media containing a biofilm, where microorganisms break down gases into energy and nutrients for growth and reproduction; thus, reducing emissions from the air. Further, the microorganism population can adapt overtime to the profile of compounds to be treated. There is some concern to whether a bypassed biofilter can regenerate microbial growth and maintain its effectiveness; however, there is inconclusive research to support this (Chen, Hoff, Cai, Koziel, & Zelle, 2009; Chen & Hoff, 2009; Hartung, Jungbluth, & Büscher, 2001; Leson & Winer, 1991; Li, Crittenden, Mihelcic, & Hautakangas, 2002; Nicolai & Janni, 1997; Swanson & Loehr, 1997).

This research views odor as a nuisance; therefore, reduction of mitigation time is critical. The Impact Based Odor Control System (IBOCS) was developed where odor control from animal facilities is limited to events that most likely would impact surrounding neighbors and substantially reduce the operation time of odor mitigation technologies. IBOCS monitors atmospheric stability and utilizes the direction of neighbors at the facility to determine if exhaust air needs to be treated. To achieve these goals, the objectives were:

1. Develop and instrument a device for controlling on-farm biofilter operation
2. Substantially reduce the operational time of any odor mitigation strategy
3. Provide cost savings to the producer and to simultaneously have a positive influence on the surrounding neighbor

Material and Methods

Facility

This research was conducted during the summer of 2009 (June through September) at a cooperator's 600 hd hybrid ventilated (i.e., fan exhaust with balance natural), deep-pit swine finisher facility located in central Iowa, USA. Two 300 hd rooms connected end-to-end were separated by a solid wall with a 2.4 m (7.9 ft) deep manure pit located below a fully-slatted floor. A wall (same wall that separated each room) separated manure pits, with the exception of equalizing channels at the bottom. Exhaust air from one 300 hd room was not treated (figure 1). The operating costs for the ventilation system with partial biofiltration was estimated to be about \$0.45 pig^{-1} (calculated at \$0.10 kw^{-1} h^{-1}). Six fictitious surrounding neighbors were assigned around the research test facility. Each neighbor was located at the compass directions relative to the source (North = 0°, continuing clockwise from north).

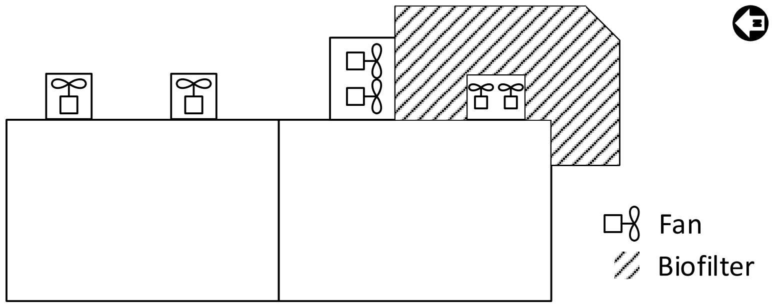

Figure 1. Layout of hybrid ventilated, deep-pit swine finisher facility located in central Iowa, USA with two 300 hd rooms connected end-to-end were separated by a solid wall with a 2.4 m (7.9 ft) deep manure pit located below a fully-slatted floor.

Biofilter

A biofilter capable of filtering 45% of the maximum required ventilation exhaust air (balance curtain-sided natural) was installed on one 300 hd room (figure 2a). Details of the site set-up and partial biofilter design and strategy can be found in Hoff et al. (2009). In order to reduce biofilter operation time, exhaust ventilation air normally routed through the biofilter was bypassed from the biofilter using a motorized louver system and exhausted to atmosphere directly (figure 2b). The decision to mitigate odors via biofiltration was based on an algorithm that tracked atmospheric stability and location of surrounding neighbors.

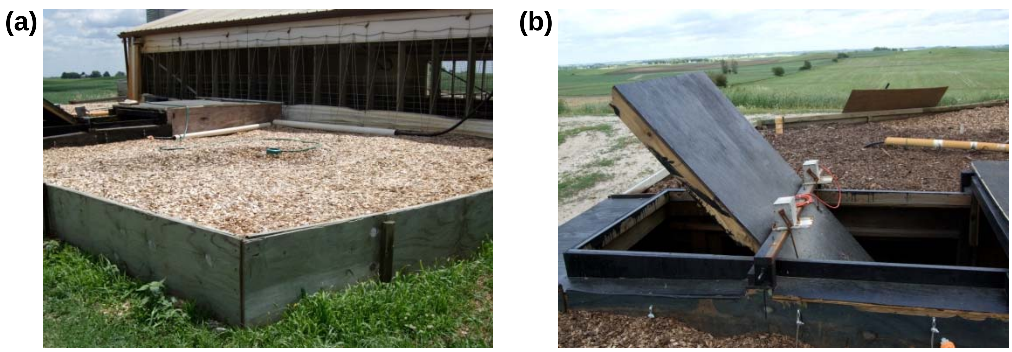

Figure 2. Test research facility with biofilter (a) and bypass louver system (b) installed (shown in bypass mode.)

Atmospheric Stability

The rise of gas plumes and subsequent dispersion of the plumes are substantially influenced by the amount of turbulence in the ambient air (Beychok, 1994). The Pasquill Stability Classes (PSC) categorize the amount of turbulence into finite levels of “stability classes”. Stability classes (table 1) are composed of classes A (most unstable or most turbulent), B (unstable), C (slightly unstable), D (neutral), E (slightly stable), and F (most stable or least turbulent). Odor plumes remain near the earth’s surface in a stable atmosphere (class F). Alternatively, an unstable atmosphere implies odor plumes rise and mix vertically close to the odor emission source (low dispersion).

Table 1. Meteorological conditions that define the Pasquill Stability Classes (Beychok, 1994).

Surface wind speed	Day-time insolation			Night-time cloud cover[4]	
$m\ s^{-1}$ (mph)	Strong[1]	Moderate[2]	Slight[3]	> 4/8 cloud	< 3/8 cloud
< 2 (4.5)	A	A-B	B	-	-
2-3 (4.5-6.7)	A-B	B	C	E	F
3-5 (6.7-11.2)	B	B-C	C	D	E
5-6 (11.2-13.4)	C	C-D	D	D	D
> 6 (13.4)	C	C	D	D	D

[1] > 143 cal $m^{-2}\ s^{-1}$
[2] 72-143 cal $m^{-2}\ s^{-1}$
[3] < 72 cal $m^{-2}\ s^{-1}$
[4] neutral class D applies to heavy overcast skies, day or night

Equipment and Sensors

IBOCS used a microprocessor (Mega 2560, Arduino LLC, Italy) to process control logic, control biofilter actuation, and collect data at a user specified interval. Data was stored on a removal flash memory via a datalogger (SD card shield V4.0, Seeed Development Limited, Shenzhen, China). Due to the lack of computer or internet connection, a real time clock (RTC Module, Freetronics Pty Ltd., Crodon South, Australia) was used to timestamp data upon collection. The following describes the sensors and accompanying uncertainty analysis used to determine the PSCs and how confidently the corresponding PSC could be determined:

Wind Speed

A detailed uncertainty analysis was performed for the three-cup anemometer (Model 12102, Gill Instruments Ltd., Hampshire, United Kingdom; table 2). Measurements in stable conditions to assess the contribution of standard error on standard uncertainty was not possible; thus, neglected but still identified to emphasize importance.

Table 2. Uncertainty analysis for wind speed sensor.

Source	Value ($m\ s^{-1}$)	Probability distribution	Divisor	Standard uncertainty ($m\ s^{-1}$)
Standard Error[1]	-	Normal	1	-
Reading Resolution	0.05	Rectangular	√3	0.03
Accuracy[2]	0.01	Rectangular	√3	0.06
Quantization Error[5]	0.03	Rectangular	√3	0.02
Combined standard uncertainty				0.07
Coverage factor, k[4]				2
Expanded uncertainty				0.14

[1] n ≥ 12
[2] ± 2% RS
[3] ADC resolution = 0.0049 V binary level^{-1}
[4] approximately 95% confidence interval and infinite degrees of freedom

Wind Direction

A detailed uncertainty analysis was performed for the wind vane (Model 03301, R.M. Young Company, Traverse City, MI, USA) that used a 10kΩ potentiometer with 8° dead band, infinite turn (table 3). Measurements in stable conditions to assess the contribution of standard error on standard uncertainty was not possible; thus, neglected but still identified to emphasize importance.

Table 3. Uncertainty analysis for wind vane.

Source	Value (°)	Probability distribution	Divisor	Standard uncertainty (°)
Standard Error[1]	-	Normal	1	-
Reading Resolution	0.05	Rectangular	√3	0.03
Accuracy	5	Rectangular	√3	2.89
Quantization Error[2]	0.18	Rectangular	√3	0.1
Combined standard uncertainty				0.32
Coverage factor, k[4]				2
Expanded uncertainty				0.64

[1] n ≥ 12
[2] ADC resolution = 0.0049 V binary level^{-1}
[3] approximately 95% confidence interval and infinite degrees of freedom

Solar Insolation

A detailed uncertainty analysis was performed for the insolation sensor (Model 6450, Davis Instruments Corp., Hayward, CA, USA) that measured within the 400 to 1100 nanometer spectrum (table 4). Measurements in stable conditions to assess the contribution of standard error on standard uncertainty was not possible; thus, neglected but still identified to emphasize importance.

Table 4. Uncertainty analysis for solar insolation senor.

Source	Value ($W m^{-2}$)	Probability distribution	Divisor	Standard uncertainty ($W m^{-2}$)
Standard Error[1]	-	Normal	1	-
Cosine Response[2]	36	Rectangular	√3	20.78
Reading Resolution	0.05	Rectangular	√3	0.03
Accuracy[3]	90	Rectangular	√3	51.96
Drift[4]	36	Rectangular	√3	20.78
Quantization Error[5]	1.47	Rectangular	√3	0.85
Combined standard uncertainty				59.7
Coverage factor, k[6]				2
Expanded uncertainty				119.4

[1] $n \geq 12$
[2] ± 2% FS, where FS = 1800 $W m^{-2}$
[3] ± 5% FS
[4] ± 2% y^{-1}
[5] ADC resolution = 0.0049 V binary $level^{-1}$
[6] approximately 95% confidence interval and infinite degrees of freedom

Control Logic

The algorithm programmed onto the microprocessor monitored wind direction and the location of surrounding neighbors, and wind speed and insolation to determine the PSC (figure 3). The decision to filter was based on an atmosphere that had a stability class C and higher (i.e., increasingly stable; table 1), and provided the wind direction was such that a neighbor would be impacted. Likewise, regardless of atmospheric stability, if the wind direction from the odor source was such that a neighbor would not be impacted, the bypass mechanism was activated allowing odorous air to be emitted directly to atmosphere without mitigation. An addition control scheme was added such that regardless of neighbor location, nighttime and low windspeed would require filtering.

The average of 12 measurements for solar insolation and wind speed were used to determine the corresponding PSC. Wind direction was handled uniquely to “safely” assess the impact region relative to a neighbor’s location. The wind direction sensor returned the direction from which the wind is coming from, which was corrected by 180° to obtain the direction the wind was headed (direction of impact). For a measured wind direction less 180°, 180° was added to the measurement, and for a measured wind direction greater than 180°, 180° was subtracted. This was to avoid a negative wind direction. A quadrant system described the potential impact regions, with a value of one assigned to that quadrant (i.e., 1, 2, 3, or 4) if the corrected wind direction was headed toward that quadrant. Starting at 0° and proceeding around the circle, eight smaller 45° sectors were assigned. If a corrected wind direction was within a sector adjacent to the quadrant (e.g., adjacent sectors 315° to 0° and 90° to 145°, for quadrant 1) a value of one was also added to the adjacent quadrant (e.g., if a corrected wind direction is 15°, quadrant 1 is assigned a one and quadrant is 4 also assigned a one). This approach increases the potential odor impact zone. For every corrected wind direction measurement, unity was added to the previous sum. The occurrence of wind directions for each quadrant was determined by dividing the number of wind directions measured in that quadrant divided by the total number of wind directions measured. A quadrant would require filtering if at least 33% of the total number of wind directions measured were present in this quadrant. This prevents against constantly filtering, if the wind frequently changing directions.

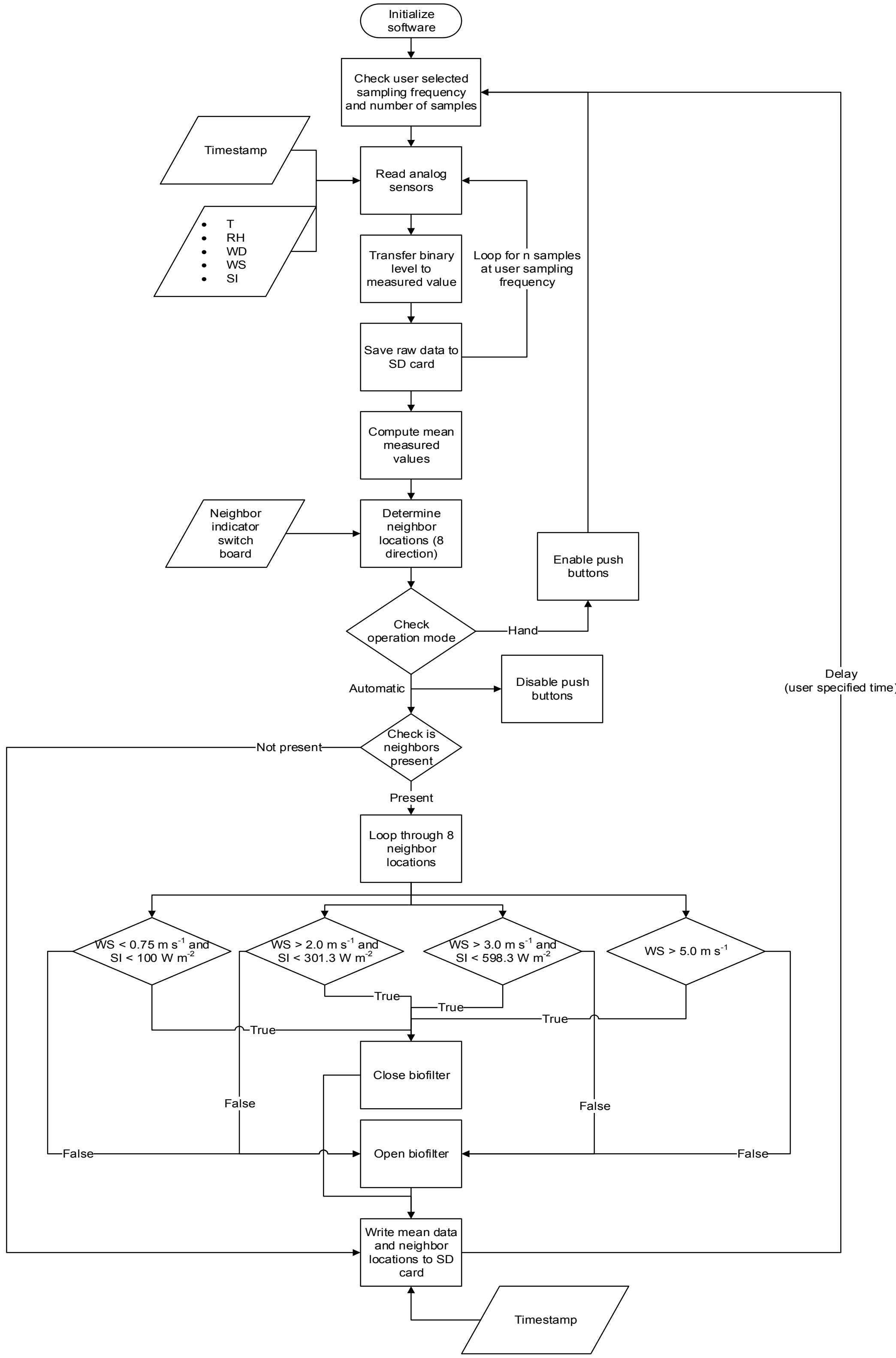

Figure 3. Control logic and software flow chart for IBOCS.

Results and Discussion

Regardless of atmospheric stability, filtering based on perceived impact from wind direction alone would reduce odor mitigation operational times by just 17.9% (figure 4). That is, if only wind direction was monitored and neighbor locations were known, odor mitigation could be bypassed for 82.1% of the time, a substantial reduction in operating costs.

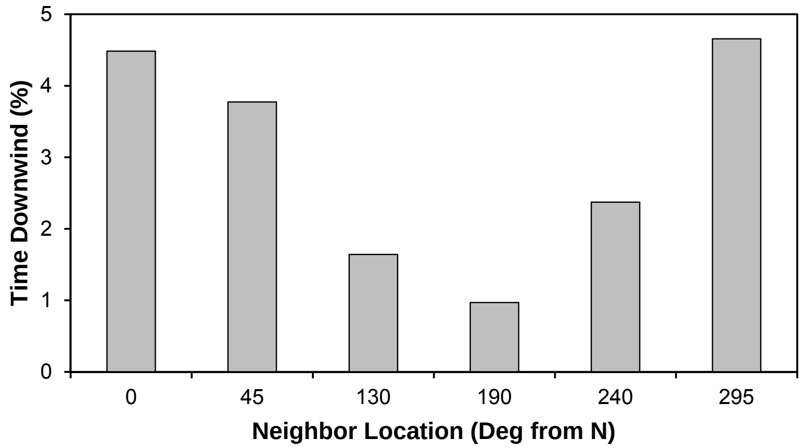

Figure 4. Test research site fictitious neighbor locations (six total) and percent time downwind for June-September, 2009, central Iowa, USA.

Biofilter operational times were further reduced when wind direction and neighbor location were coupled with the PSC criteria with operation time going from 17.9% (wind direction only; figure 4) to 7.1% total time (figure 5). That is, 92.9% of the time, odor mitigation was not required for the six neighbors modeled at this facility. Theoretically, the estimated \$0.45 pig^{-1} fan operational costs associated with the original biofiltration strategy has been reduced to \$0.03 pig^{-1}, while still maintaining considerable odor impact control to the surrounding neighbors.

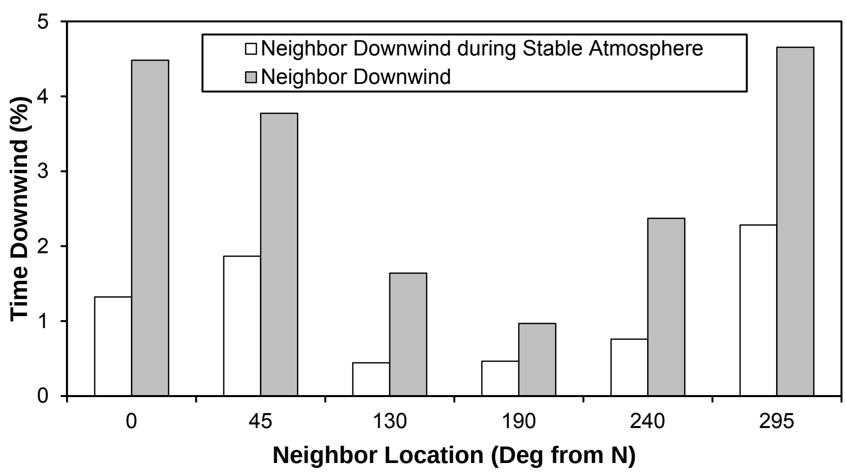

Figure 5. Test research site fictitious neighbor locations (six total) and percent time downwind. Addition of the determining the PSC further reduced biofilter operation compared with just filtering based on wind direction alone.

Conclusions

The Impact Based Odor Control System (IBOCS) was developed to regulate any ON/OFF odor mitigation device (such as a biofilter, wet scrubber, etc.) implemented to treat swine facility exhaust air. When odor control from animal facilities is limited to events that most likely would impact surrounding neighbors, filtering would be applied. This approach is economical and effective, and maximizes odor reduction potential when most needed. IBOCS reduced biofilter operational time from 17.9% (wind direction only filtering control) to 7.1% total time using a combination of wind speed and solar insolation to determine atmospheric stability (as classified by the PSCs).

In theory, the estimated \$0.45 pig^{-1} fan operational costs associated with the original biofiltration strategy has been reduced to \$0.03 pig^{-1}, while still maintaining considerable odor impact control to the surrounding neighbors. These results are useful to producers, community members, and regulators for development of best management practices for swine odor.

A common theme in odor regulation discussions is to recommend mitigating odors for all building exhaust air, all the time. Not only is this approach extremely costly to the producer, it is not supported by scientific evidence or findings. If odor is to be controlled based on nuisance, then IBOCS represents a cost effective technique that also provides substantial odor impact control to surrounding neighbors. Further research work needs to continue to develop Impact-based odor control strategies that lessen the need for substantial source odor control and shift the focus on the anticipated odor exposure impact on neighboring receptors.

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