Mitigation of Odor and Pathogens from CAFOs with UV/TIO_2: Exploring Cost Effectiveness

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Species: Swine, Poultry
Use Area: Animal Housing
Technology Category: UV photocatalysis
Air Pollutants Mitigated: Volatile Organic Carbon, odor, and pathogens

Description:

Livestock operations are sources of aerial emissions of odor, volatile organic compounds (VOCs), ammonia, hydrogen sulfide, and bioaerosols, including pathogens (National Research Council, 2003). At the same time these operations are potentially threatened with infectious diseases impacting national economies and food supply security. Comprehensive solutions to these multidisciplinary problems are needed. Our long-term objective is to develop and apply a novel treatment technology that would minimize the environmental impact of swine operations and at the same time would protect them and the public from the spread of infectious diseases.

This paper reports feasibility tests of lab-scale treatment of aerial emissions of selected VOCs responsible for livestock odor and inactivation of airborne pathogens by low-wattage UV light. The long-term goal is to develop cost-effective technology for the simultaneous treatment of odor and pathogens in livestock housing through logical progression of testing from lab-scale, through pilot-scale and finally at commercial scale. Such treatment would be applicable to both the inflow (for airborne pathogen control) and outflow air (for odor and pathogen control) at typical existing and new mechanically-ventilated barns.

Several target VOCs responsible for livestock odors were selected for testing effectiveness of UV light on odor. The selection of key odorants for lab-scale tests was based on previous work (Wright et al., 2005; Koziel et al., 2006, Bulliner et al., 2006). These include p-cresol, sulfur-containing VOCs, and volatile fatty acids. The effects of UV treatment time on the effectiveness of gas and odor removal were tested. The treatment times, gas flow rates, and UV energy used were then extrapolated to estimate theoretical cost of UV treatment of odor for typical ventilation rates and electricity cost at a swine finish operation in Iowa.

Mitigation Mechanism:

Odor and target VOCs responsible for livestock odor are mitigated by UV-185 nm ('deep' UV) in presence of TiO_2 as a catalyst into less odorous or odorless products such as CO_2 and H_2O. The chemistry behind can be shown as follows:

$$TiO_2 \xrightarrow{h\nu} e^- + h^+$$
$$h^+ + H_2O \rightarrow OH\bullet + H^+ \text{ (in presence of water vapor)}$$
$$e^- + O_2 \rightarrow O_2^-\bullet$$
$$O_2^-\bullet + H^+ \rightarrow HO_2\bullet$$
$$\text{VOCs/Odorants} + oxidants \rightarrow \text{(less odorous) partially oxidized species} + CO_2 + H_2O$$

The effectiveness of UV light in treating VOCs and pathogens is well known in water treatment applications. Relatively little is known about gas-phase chemistry of odorous VOCs and inactivation of airborne pathogens with UV (Yang et al., 2007). Several advantages exist for gas-phase UV treatment compared to aqueous phase. These include: (1) lower levels of UV energy are needed compared with liquid phase; (2) degradation rates in air are typically higher; (3) gas-phase reactions allow the application of analytical tools enabling to monitor reaction rates and elucidate mechanisms; (4) the diffusion of reagents and products is much faster compared with liquid phase; (5) HO•

scavengers present in water do not interfere; (6) electron scavengers such as oxygen are rarely limiting; and (7) the lower absorption of photons by air compared with water.

With the addition of TiO_2 photocatalyst beds, additional oxidative processes occur at the gas-solid interface, through entirely different mechanisms that offer additional pathways to degrade recalcitrant VOCs. By nature, the catalyst beds are self-cleaning under exposure to UV light and air and add additional efficiency to the oxidative system. Titanium dioxide-mediated photocatalysis have also been shown to be effective at inactivation of pathogens.

Applicability:

The long-term goal is to develop cost-effective technology for the simultaneous treatment of odor and pathogens in livestock and poultry barns with mechanical ventilation. Such treatment would be applicable to both the inflow and outflow air. The inflow air could be treated with UV light for pathogens in the times of highly infectious diseases during which an isolation and protection of farm animals might be needed. Treatment of exhaust air with UV light would be used for odor and pathogens. Commercial scale systems would be applicable to new barns as well as to retrofit existing barns.

In this research, we measured the effectiveness of odor treatment and pathogen inactivation in laboratory scale. Summary of chemical percent reduction for target gases (selected odor-causing VOCs and H_2S) and % reduction of odor caused by each target gas is presented in Tables 1 and 2. Almost 100% removal was achieved for all the compounds tested except H_2S and dimethylsulfide using only 1 sec irradiation. Longer UV irradiation times resulted in improved percent reduction of target compounds and odor. Of specific interest is the removal of *p*-cresol which has been recognized as priority odorant responsible for the characteristic livestock odor (Wright et al., 2005; Koziel et al., 2006; Bulliner et al., 2006).

Table 1 – Chemical reduction% of target gases with different UV exposure times and TiO_2 catalyst

	% Reduction = (Control-Treatment)/Control*100%							
UV exposure (sec)	1	3	5	7	10	30	60	300
H_2S	10.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Methylmercaptan	80.0	81.4	96.3	87.1	57.9	100.0	100.0	100.0
Ethylmercaptan	94.7	96.5	100.0	96.9	59.2	100.0	100.0	100.0
Dimethylsulfide	48.2	18.6	47.3	85.5	70.4	99.8	100.0	100.0
Butylmercaptan	94.3	100.0	100.0	100.0	78.3	90.4	100.0	100.0
Acetic acid	99.4	99.5	99.1	99.4	97.1	97.1	98.9	100.0
Propanoic acid	99.9	99.9	99.9	100.0	99.7	99.8	99.6	100.0
Butyric acid	99.9	99.8	99.9	99.9	99.7	100.0	99.5	100.0
Isovaleric acid	99.6	99.3	99.3	99.5	99.7	99.8	98.9	99.9
P-cresol	99.5	99.2	99.4	97.2	97.5	99.3	98.0	99.9

Table 2 - Odor reduction% of target gases with different UV exposure time and 25 mg TiO_2 catalyst

	Reduction% = (Control-Treatment)/Control*100%							
UV exposure (sec)	1	3	5	7	10	30	60	300
H_2S	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Methylmercaptan	38.0	52.0	60.0	62.0	38.0	100.0	100.0	100.0
Ethylmercaptan	51.0	58.8	100.0	100.0	31.4	100.0	100.0	100.0
Dimethylsulfide	42.9	64.3	68.6	71.4	47.1	70.0	100.0	100.0
Butylmercaptan	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Acetic acid	85.4	92.7	100.0	100.0	100.0	100.0	72.0	100.0
Propanoic acid	82.1	100.0	100.0	100.0	64.3	100.0	100.0	100.0
Butyric acid	81.8	87.0	100.0	100.0	100.0	100.0	100.0	100.0
Isovaleric acid	73.5	73.5	78.3	80.7	100.0	100.0	100.0	100.0
P-cresol	89.0	90.2	91.5	82.9	85.4	85.4	100.0	100.0

Limitations:

Our team is still working on addressing some of the potential limitations of UV treatment. These include (a) testing the shortest possible treatment times that are consistent with fast air flow in a mechanically ventilated barn, (b) the presence of particulate matter (PM), and (c) production of reactive ozone gas during UV irradiation.

Cost:

Electricity cost for UV treatment is summarized in Table 3. This cost was estimated assuming that certain variables in laboratory scale such as the treatment time, UV lamp wattage, treated airflow rate, respectively, can be used to extrapolate the cost of electricity in full scale swine finisher barn (Table 4). It was assumed that the same lamp is treating full-scale ventilation airflow rate at the rural electricity cost. Table 3 summarizes the cost of electricity for 3 growing cycles on a real swine operation in central Iowa and the cost of UV as fraction of the total electricity cost. Cost of electricity associated with UV treatment is also presented on the basic of continuous operation as well as the intermittent operation for 12, 8, and 1 hr, respectively.

Table 3. Estimated electricity cost associated with UV treatment per pig during three growing cycles

	Cycle1 (01/30/04~06/18/04)	Cycle2 (06/25/04~11/24/04)	Cycle3 (12/16/04~04/24/05)
Season	Transitional	Warm	Cool
Mean air flow (m^3/s)	723.8	1124.6	546.6
Total air flow per cycle (m^3)	6.25E+07	9.72E+07	4.72E+07
Average # of pigs sold	828	810	950
UV electricity cost ($)	191.9	298.2	144.9
Based on UV lamp operating for 24 hrs per day			
UV electricity cost/pig sold ($)	0.23	0.37	0.15
UV treatment/ total electricity (%)	8.50	13.49	5.59
Based on UV lamp operating for 12 hrs per day			
UV electricity cost/pig sold ($)	0.116	0.184	0.076
UV treatment/ total electricity (%)	4.25	6.74	2.79
Based on UV lamp operating for 8 hrs per day			
UV electricity cost/pig sold ($)	0.077	0.123	0.051
UV treatment/ total electricity (%)	2.83	4.50	1.86
Based on UV lamp operating for 1 hr per day			
UV electricity cost/pig sold ($)	0.010	0.015	0.006
UV treatment/ total electricity (%)	0.35	0.56	0.23

Table 4. Assumptions used for extrapolation of electricity cost in Table 3.

cost of KWh ($)	0.087	Electricity per UV reactor (KWh)	7.06E-09
light intensity (mW/cm^2)	0.25	Electricity cost per UV reactor ($)	6.14E-10
reactor surface area (cm^2)	101.6	Volume of UV reactor (mL)	200
treatment time (sec)	1	cost of total UV treatment ($/m^3)	3.07E-06

For a continuously operating system, the estimated average electricity cost of UV treatment per pig sold was $0.23, $0.37, and $0.15, for transitional, warm and cool seasons, respectively. The cost can be further reduced by intermittently operating the treatment system on as needed basis. For example, if UV lamp was to be operated for 1hr per day, the cost would be lowered to $0.006 and $0.015 (Table 3). The fraction of electricity cost for UV treatment would be only 0.23 to 0.56%.

Implementation:

To date, the UV treatment for odor mitigation and pathogen inactivation is still at laboratory scale. The illustration of full scale application to exhaust air is shown in Figure 1. Additional extension of the exhaust fan nozzle could be installed to divert the effluent upwards. This additional chimney-like channel could be used to (a) mount UV lamp(s) and (b) to improve dispersion of exhaust air. It is also an advantage that the UV lamps are activated by simple on/off switch. Theoretically, each fan could be retrofitted with such add-on system.

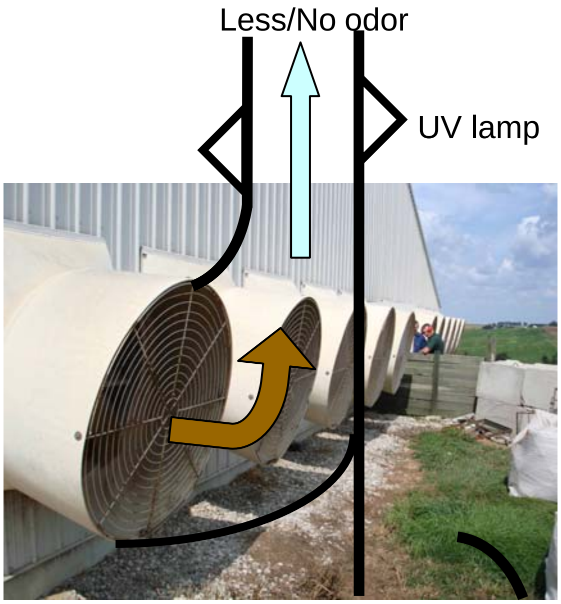

Figure 1. Schematic of scaled up UV treatment of exhaust air for odor and inactivation of airborne pathogens.

Technology Summary:

Odor and target VOCs responsible for livestock odor are mitigated by UV-185 nm (‘deep’ UV) in presence of TiO_2 as a catalyst into less odorous or odorless products such as CO_2 and H_2O. Percent removals from 80 to 99% were measured in lab-scale experiments involving simulated livestock VOCs/odorants and 1 sec irradiation with a low wattage 5.5 W lamp. Selected VOCs simulating livestock odor included p-cresol, sulfur-containing VOCs, and volatile fatty acids. Treatment cost of $0.25 per pig and continuous operation during growing cycle was estimated when the lab-scale results were extrapolated to typical ventilation rates and electricity cost at a swine finish operation in rural Iowa. The long-term goal is to develop cost-effective technology for the simultaneous treatment of odor and pathogens in livestock housing through logical progression of testing from lab-scale, through pilot-scale and finally at commercial scale. Such treatment would be applicable to both the inflow (for airborne pathogen control) and outflow air (for odor and pathogen control) at typical existing and new mechanically-ventilated barns.

Additional Resources:

http://www.abe.iastate.edu/odor

Acknowledgments:

The authors gratefully acknowledge the financial support provided by National Pork Board and Binational Agricultural Research and Development Fund.

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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
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