RESEARCH REPORT

ENVIRONMENT

Title: Simultaneous treatment of swine odor and airborne pathogens by UV254 light - **NPB #07-091**

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Industry Summary: A 1-year feasibility study was conducted, aiming to explore the effectiveness of UV light for simultaneous treatment of odor, odorous VOCs and airborne pathogen emissions from swine operations. Several operating parameters were tested in laboratory scale including: UV wavelength, presence of photocatalyst, the effects of UV dose, and the effects of air relative humidity and air temperature. Removal and conversion of odor, target gases responsible for causing swine odor such as odorous sulfur-containing volatile organic compounds (SVOCs), volatile fatty acids (VFAs), phenolics, ammonia, and airborne pathogens was tested. Up to 100% removal of odor, 100% of S-VOCs, 100% VFAs, and 100% phenolics, and up to 65% of ammonia was achieved with optimized UV treatment. Treatments involving 185 nm UV band and treatments involving the presence of photocatalyst (TiO_2) were more efficient in removal and conversion of odorous gases and odor in flowing air. In addition, greater than 99% inactivation was achieved for both the swine influenza virus (SIV) and bovine viral diarrhea virus (BVDV) which were both highly susceptible to 254 nm UV inactivation. The extrapolated estimate of the operational cost of treatment would range from $0.15 to $0.60 per finisher pig based on the lab scale results from this research. This figure represents significantly lower cost compared with the cost of biofiltration or air scrubbing. These results warrant further investigations involving testing the effects of dust on UV treatment and experiments in pilot scale. For more information please contact – Dr. Jacek Koziel, Department of Agricultural and Biosystems Engineering, Iowa State University at koziel@iastate.edu or 515-294-4206.

Scientific Abstract: A feasibility study was conducted, aiming to explore the effectiveness of UV light for simultaneous treatment of odor, odorous VOCs and airborne pathogen emissions from swine operations. Several operating parameters were tested in laboratory scale including: UV wavelength, presence of photocatalyst, the effects of UV dose, and the effects of air relative humidity and air temperature. Removal and conversion of odor, target gases responsible for causing swine odor such as odorous sulfur-containing volatile organic compounds (SVOCs), volatile fatty acids (VFAs), phenolics, ammonia, and airborne pathogens was tested. Up to 100% removal of odor, 100% of S-VOCs, 100% VFAs, and 100% phenolics, and up to 65% of ammonia was achieved with optimized UV treatment. Treatments involving 185 nm UV band and treatments involving the presence of photocatalyst (TiO_2) were more efficient in removal and

conversion of odorous gases and odor in flowing air. There were no limitations to the shortest treatment time. The treatment efficiency was proportional to the UV dose. In addition, greater than 99% inactivation was achieved for both the swine influenza virus (SIV) and bovine viral diarrhea virus (BVDV) which were both highly susceptible to 254 nm UV inactivation. The estimate of the operational cost of treatment was based on measured emissions of several odorous VOCs from full scale, commercial swine farm ranges from $0.15 to $0.60 per finisher pig.

Introduction: This research addressed National Pork Board 2007 research focus Categories A (Environment – control / mitigation of odor), B (Swine Health - Porcine Respiratory Disease Complex), and H (Public Health - zoonotic pathogens with potential public health significance). The long-term goal is to develop cost-effective technology for the simultaneous treatment of odor and pathogens in swine housing in order to limit their impact on air quality and health (human and animal). The proposed study brought together several multi-year projects and a unique collaboration between air quality engineers and experts in infectious diseases of swine. In separate experiments, our previous work with UV254 demonstrated significant removal of (1) odor and the specific gases most responsible for swine odor and (2) significant inactivation of swine pathogens. Building on this work, we proposed to take the next logical step, i.e., test the use UV254 to simultaneously control odor and inactivate airborne pathogens under a range of environmental conditions (relative humidity and temperature).

The core question this research addresses was: can we eliminate odor and inactivate airborne pathogens simultaneously in a treatment time that is consistent with air turnover rates and environmental conditions in swine barns? Estimating the rate at which odor, odorous gases, and pathogens are inactivated when exposed to UV254 is critical to answer the core question in this research.

Objectives: Determine the dose of UV254 required for inactivation of odor, odor-causing gases, and airborne pathogens (swine influenza virus (SIV) and bovine viral diarrhea virus (BVDV)) in simultaneous exposure-treatment with UV254 light.

Materials & Methods:

Chemicals and standard gases. A standard gas generation system was used to generate nine odorous VOCs (S-VOCs, VFAs and phenolics) & H_2S. Ammonia was from EPA-grade standard gas cylinder. Odorous gases emitted from swine manure were generated by purging manure with air. All gases were delivered to a flow-through photoreactor (Yang *et al.*, 2007).
Photoreactor and UV light sources. A flow-through reaction chamber was designed and built for simultaneous destruction of VOCs and pathogens (Fig. 1). The effects of several variables on the VOC removals, including treatment time, UV light energy dose, relative humidity (RH), temperature (T), initial VOCs concentration, gas flow rate, presence of TiO_2, UV light wavelength and the presence of other gases, were tested.

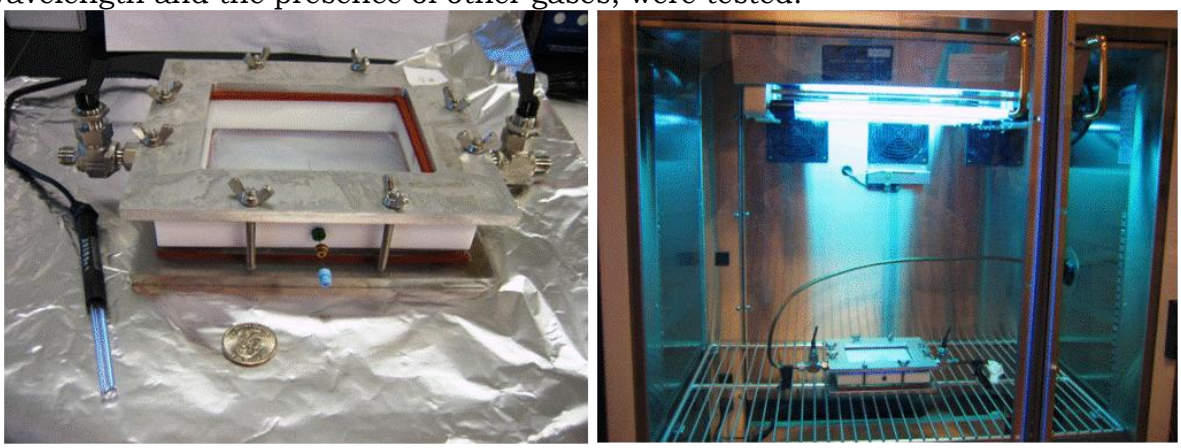

Figure 1. Schematic of photoreaction chamber (left) and T/RH control chamber (right) with UV lamps for controlled UV treatment of odorous gases in flowing air.

Two types of 10W UV mercury lamps were used in parallel, i.e., lamps have principal outputs at 254 nm and 'deep' UV lamps with 185 nm band. The photoreactor temperature was kept at 25°C for all experiments.

Photocatalyst preparation. Thin films of Degussa P25 TiO_2 (Degussa, Germany) was used as coating inside the photoreactor (Yang *et al.*, 2007, Yang *et al.*, 2008).

Analytical methods. All gas sampling was performed with solid-phase microextraction (SPME) except for NH_3 which was measured with colorimetric method. Gas samples were analyzed on a multidimensional GC-MS-O system and forced-choice olfactometer. Odor concentrations were measured at the Olfactometry Laboratory at Iowa State University. Odor was accessed by a forced-choice, dynamic-dilution olfactometer at a total odor basis with four panelists assessing odor detector threshold (ODT) from air samples collected in a 10 liters Tedlar bags.

Data analysis. Effectiveness of treatment was assessed as percent removal for each target compound or odor, and was calculated as follows:

$$\%R = \frac{(Control - Treatment)}{Control} * 100\ \%$$

where % R = percent removal (or percent conversion); Control and Treatment = measured odor concentrations or peak areas measured with MS detector for target gases for the untreated and treated gas, respectively.

Pathogens. The removal of pathogens was assessed in a static system (Fig. 2).

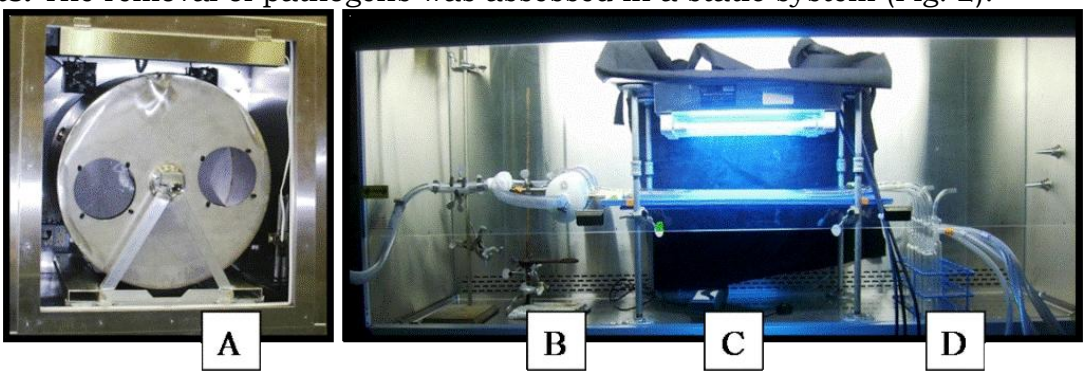

Figure 2. Dynamic aerosol toroid [A] for holding virus aerosols housed in an environmental chamber capable holding a range of temperatures (10°F to 90°F; -12.2-32.2°C) and relative humidities (10% to 90%). Aerosolized virus is drawn into a manifold [B], passed across of field of UV exposure [C], collected in samplers (impingers) [D], and assayed for infectious virus. Sections [B, C, D] are housed in a biosafety cabinet (NuAire® Series 33 Class II Type B2).

Results:

The removal and conversion of nine odorous VOCs (mixed in a standard gas mixture) are summarized in Table 1 and Fig. 3-5. The removal and conversion of selected odorous gases emitted from for real swine manure are summarized in Table 2.

Table 1. $UV_{185+254}$+TiO_2: summary of measured gas concentrations in UV-treated gas and percent reduction (MDL=method detection limit).

Compound name	Treatment time (sec) and UV energy dose measured at 254nm (J)										Removal [c] (ng/J)
	2.5 sec		19 sec		37 sec		56 sec		112 sec		
	0.02 J		2.90 J		5.64 J		8.54 J		17.1 J		
	C_{gas}[a]	R[b] (%)	C_{gas}	R (%)	C_{gas}	R (%)	C_{gas}	R (%)	C_{gas}	R (%)	
Methylmercaptan	0.755	22.1	0.297	70.9	0.308	78.8	0.151	98.0	MDL	99.8	4.72
Ethyl Mercaptan	1.55	25.2	0.853	66.0	0.899	73.2	0.563	97.9	MDL	99.7	14.6
Dimethyl Sulfide	0.428	23.5	0.267	63.6	0.273	67.4	0.187	92.2	MDL	99.6	4.94
Butyl Mercaptan	0.224	29.3	0.112	65.8	0.121	75.3	0.073	94.5	MDL	99.5	8.68
Acetic Acid	0.554	-16.0	0.227	51.4	0.212	61.2	0.113	80.1	0.071	93.1	11.6
Propanoic Acid	0.456	7.16	0.198	59.9	0.185	65.7	0.084	85.0	0.042	96.7	8.65
Butyric Acid	0.543	19.8	0.210	56.7	0.280	63.1	0.114	83.8	0.074	97.1	15.7
Isovaleric Acid	1.90	21.1	0.563	51.7	1.07	57.3	0.287	80.2	0.133	97.8	49.2
p-Cresol	3.00	25.4	0.637	64.6	1.11	72.8	0.143	91.7	0.019	99.9	78.9

Note: a) the unit for C_{gas} is ng/mL; b) R refers to % reduction (defined above) c) removal rate defined as removal of mass per unit of UV energy (dose).

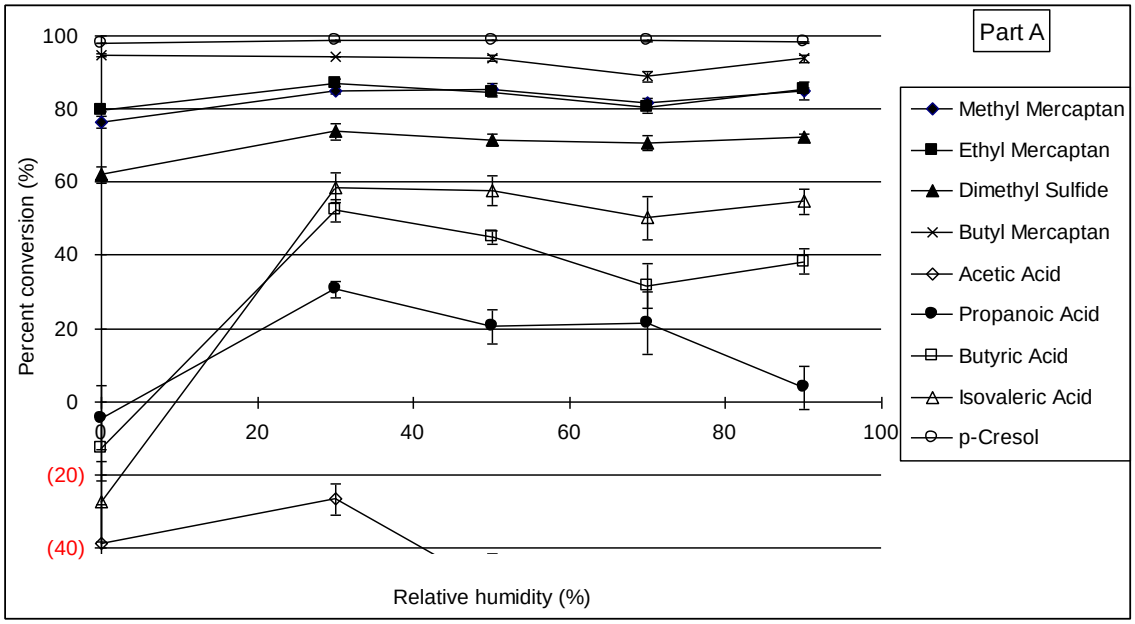

Figure 3. Effect of relative humidity (%) on percent removal and conversion of target odorous gases with $UV_{185+254}$ with photocatalyst.

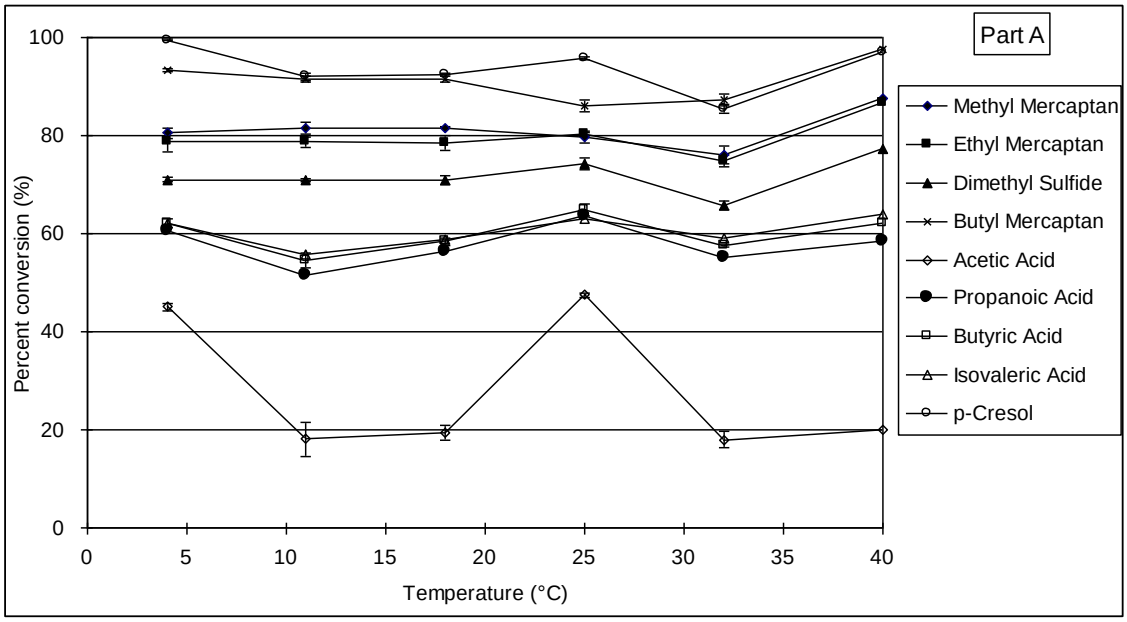

Figure 4. Effect of temperature (°C) on percent conversion of target odorous gases with $UV_{185+254}$ with photocatalyst.

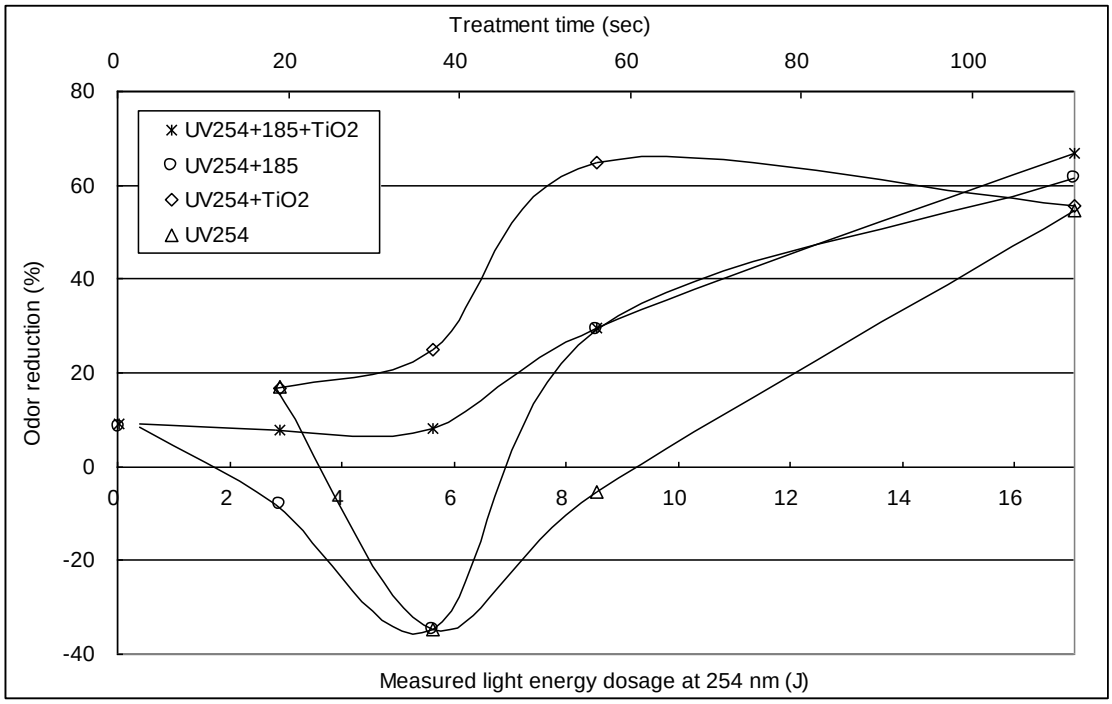

Figure 5. Effect of treatment time on total odor reduction. Total odor reduction (expressed as ODT) as a function of measured light energy dosage at 254 nm (treatment time). The ODT of each gas sample was assessed by ≥4 trained panelists using a forced-choice dynamic-dilution olfactometer at Iowa State University.

Table 2. Percent reduction (%) of MS detector response (peak area counts) of selected odorous VOCs emitted **from fresh manure** with UV treatment with and without photocatalyst.

Compound name	**Percent reduction (%)**	
	$UV_{185+254}$+TiO_2	**$UV_{185+254}$**
Dimethyl disulfide	MDL*	MDL
Acetic acid	-1723	-2928
Butyric acid	30.1	-22.1
Isovaleric Acid	26.2	20.3
Hexanoic acid	MDL	18.8
Phenol	94.7	67.6
p-Cresol	MDL	79.3
*Note: MDL is method detection limit, which means the peak area is beyond the detection limit. Therefore the percent reduction is ~100%.		

Treatment of ammonia with UV. Table 3 summarizes the results obtained for ammonia removal. Highest removal (up to 65.1%) was obtained using $UV_{185+254}$+TiO_2 treatment.

Table 3. Percent reduction (%) of NH_3 concentration (ppm).

	With VOCs		**Without VOCs**	
UV Treatment type	Dry air	Humid air	Dry air	Humid air
$UV_{185+254}$+TiO_2	38.6	65.1	58.7	54.5
$UV_{185+254}$	23.7	18.1	13.5	17.2
UV_{254}+TiO_2	34.2	34.9	44.4	43.4
UV_{254}	5.26	2.41	2.38	0.00

Estimation of the UV_{254} inactivation rate (k-value) of viral pathogens

Inactivation rates (k-value) were determined for 2 viral pathogens - swine influenza virus (SIV), bovine viral diarrhea virus (BVDV) (plus PRRSV and reovirus work under a separately-funded project). This work was conducted under "static" conditions (virus in liquid medium) using "off-the-shelf" UV hardware from commercial manufacturers (American Ultraviolet Co., Lebanon IN). Fig. 6 shows that SIV, BVDV (used as a surrogate for CSFV), and PRRSV are highly susceptible to UV_{254} inactivation. Reovirus, a virus resistant to UV_{254} inactivation, was only included for comparison. The data suggest that UV could be a practical and cost-effective method to inactivate important airborne pathogens of swine.

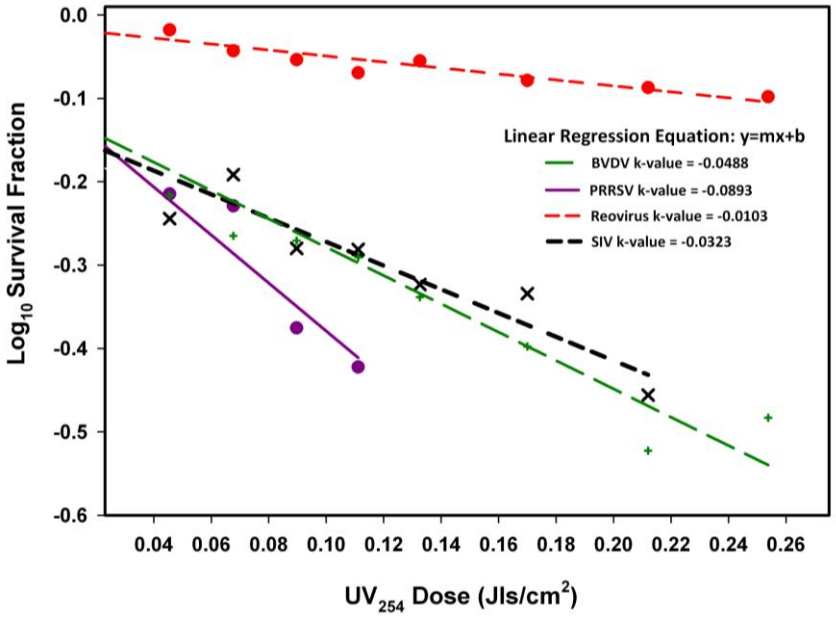

Figure 6. Inactivation rate of viral pathogens. The slope of the line reflects the pathogen's susceptibility to UV irradiation.

Discussion: The control of odor and pathogens generated in commercial swine production is a critical need. This study tested the potential for using currently available UV technology in of the degradation of most offensive swine odorants, NH_3, and model pathogens (SIV, BVDV). Such UV light-based technology is suitable for further development and ultimate application for ventilation air. The UV technology could be applied to exhaust air (to treat emissions) and inlet air (to prevent the spread of infectious diseases) for new and existing operations.

The results of this study could be summarized as follows:
(1) UV light is very effective (up to 100%) in removing odor, VOCs and gases responsible for swine odor in laboratory scale using both the standard gases as well as gases emitted from swine manure.
(2) $UV_{185+254}$ ('deep' UV) with photocatalysts was the most efficient abatement option among all four treatment options involved. In terms of treatment effectiveness, the four treatment options follow an order of $UV_{185+254} + TiO_2 > UV_{254}+TiO_2 > UV_{185+254} > UV_{254}$.
(3) Percent conversion of tested VOCs was linearly correlated with the UV light energy dose. Thus, the short treatment required by the fast moving ventilation air is not a limitation, since the same odor and VOC removal conversion can be achieved by increasing the dose.
(4) Air temperature does not have an effect on the treatment efficiency of most target odorous compounds in this research within the range of 4 to 40 °C (i.e., well within the range of temperatures encountered in typical swine housing.
(5) No significant difference in the treatment efficiency was observed for most of target odorous compounds in this research within the range of 0 to 90% (i.e., within the typical range of humidity in swine housing).
(6) The use of photocatalysts (TiO_2) improved the treatment effectiveness of some VOCs, especially VFAs.
(7) Up to 65% removal of ammonia was achieved with UV treatment.
(8) UV could be a practical and cost-effective method to inactivate important airborne pathogens of swine.

Additional funding for treatment optimization (simultaneous treatment of odor and airborne pathogens in one experimental setup, optimization of treatment to lowest energy use, testing effects of dust removal) would be needed to address these remaining questions and move the technology from laboratory scale to commercial scale. Comprehensive solutions to swine aerial emissions are expected to be even more urgent in the future. Thus, this study addressed several critically important issues confronting pork producers, but also has a broader

applicability to homeland security, human/animal health, indoor air quality and hazardous waste treatment.

Publications from this research:

1. Koziel, J.A, X. Yang, S. Zhang, L. Cai, S. J. Hoff, H. J. Leeuwen, T. Cutler, J. Zimmerman, W. S. Jenks, Y. Laor, U. Ravid, R. Armon. 2008. Treatment of livestock odor and pathogens with ultraviolet photocatalysis. In the proceedings of *The 3rd IWA Odour and VOCs Conference*, Barcelona, Spain, October 2008.
2. Yang, X., J.A. Koziel, T. Cutler, S. Zhang, J. Zimmerman, S.J. Hoff, W. Jenks, J (Hans) van Leeuwen, J. Harmon, C. Faulhaber, Y. Laor, U. Ravid, R. Armon. 2008. Treatment of livestock odor and pathogens with ultraviolet light. ASABE Paper # 085198. *ASABE Annual International Meeting*. Providence, RI, June, 2008.
3. Koziel, J.A., X. Yang, T. Cutler, S. Zhang, J. Zimmerman, S. J. Hoff, W. Jenks, Y. Laor, U. Ravid, R. Armon, J.H. van Leeuwen. 2008. Mitigation of odor and pathogens from CAFAs with UV/TiO_2: exploring cost effectiveness. In the proceedings of the *Mitigating Air Emissions from Animal Feeding Operations Conference*. Des Moines, IA, May, 2008.
4. Yang, Y., J.A. Koziel, L. Cai, S. Hoff, J. Harmon, J.H. van Leeuwen, W.S. Jenks, J. Zimmerman, T. Cutler. 2007. Novel treatment of odor and VOCs using UV photolysis. ASABE paper # 074139. *ASABE Annual International Meeting*. Minneapolis, MN, June, 2007.
5. Koziel, J.A., X. Yang, T. Cutler, S. Zhang, J. Zimmerman, S. Hoff, W.S. Jenks, J.H. van Leeuwen, Y. Laor, U. Ravid, R. Armon. 2008. Treatment of livestock odor and pathogens with ultraviolet photocatalysis. Abstract OP-575 Abstract in the proceedings of the *AgEng 2008 International Conference on Agricultural Engineering and Industry Exhibition*, Hersonissos, Greece, June, 2008.
6. Koziel, J.A., J. Zimmerman, S. Hoff, H. van Leeuwen, W. Jenks. Research Brief: Simultaneous treatment of odor, VOCs, H_2S, NH_3, and pathogens with UV light. 2008 Annual Report of the S-1032: Improving the Sustainability of Livestock and Poultry Production in the United States.

Several manuscripts are in preparation for peer-review.