2021

Pilot-scale UV-A light treatment for mitigation of NH3, H2S, GHGs, VOCs, odor, and O3 inside the poultry barn

Myeongseong Lee
Iowa State University and Chungnam National University, leefame@iastate.edu

Jacek A. Koziel
Iowa State University, koziel@iastate.edu

Peiyang Li
Iowa State University, peiyangl@iastate.edu

Heekwon Ahn
Iowa State University and Chungnam National University

Jisoo Wi
Iowa State University and Chungnam National University

See next page for additional authors

Pilot-scale UV-A light treatment for mitigation of NH3, H2S, GHGs, VOCs, odor, and O3 inside the poultry barn

Abstract

Poultry farmers are producing eggs, meat, and feathers with increased efficiency and lower carbon footprint. Technologies to address concerns about the indoor air quality inside barns and the gaseous emissions from farms to the atmosphere continue to be among industry priorities. We have been developing and scaling up a UV treatment that has the potential to reduce odor and other gases on the farm-scale. In our recent laboratory-scale study, the use of UV-A and a special TiO_2-based photocatalyst reduced concentrations of several important air pollutants (NH_3, CO_2, N_2O, O_3) without impact on H_2S & CH_4. Therefore, this research's objectives were to (1) scale-up of the UV treatment to pilot-scale, (2) evaluate the mitigation of odor and odorous VOCs. The effects of a photocatalyst's presence (photocatalysis & photolysis), UV intensity (LED & fluorescent), and treatment time we studied in the pilot-scale experiments inside a poultry barn. The results of pilot-scale experiments were consistent with the lab-scale: the % reduction under photocatalysis was generally higher than photolysis. In addition, the % reduction of target gases at a high light intensity and long treatment time was higher. The % reduction of NH_3 was 5~9%. There was no impact on H_2S, CH_4, and CO_2 under any experimental conditions. N_2O & O_3 concentrations were reduced at 6~12% & 87~100% by both photolysis & photocatalysis. In addition, concentrations of several VOCs responsible for livestock odor were reduced from 26~62% and increased with treatment time & light intensity. The odor was reduced by 18%. Photolysis treatment reduced concentrations of N_2O, VOCs, and O_3, only. Further scale-up and research at the farm-scale are warranted.

Keywords

Disciplines

Agriculture | Bioresource and Agricultural Engineering | Environmental Chemistry | Environmental Health

Comments

Authors

Myeongseong Lee, Jacek A. Koziel, Peiyang Li, Heekwon Ahn, Jisoo Wi, Baitong Chen, Zhanibek Meiirkhanuly, Chumki Banik, and William S. Jenks

Pilot-scale UV-A light treatment for mitigation of NH₃, H₂S, GHGs, VOCs, odor, and O₃ inside the poultry barn

Myeongseong Lee [1,2], Jacek A. Koziel [2,*], Peiyang Li [2], Heekwon Ahn [1,2], Jisoo Wi [1,2], Baitong Chen [2], Zhanibek Meiirkhanuly [2], Chumki Banik [2] and William Jenks [3]

[1]   Department of Animal Biosystems Sciences, Chungnam National University, Daejeon 34134, Rep. of Korea

[2]   Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA 50011, USA

[3]   Department of Chemistry, Iowa State University, Ames, IA 50011, USA

*Correspondence: koziel@iastate.edu

ABSTRACT. *Poultry farmers are producing eggs, meat, and feathers with increased efficiency and lower carbon footprint. Technologies to address concerns about the indoor air quality inside barns and the gaseous emissions from farms to the atmosphere continue to be among industry priorities. We have been developing and scaling up a UV treatment that has the potential to reduce odor and other gases on the farm-scale. In our recent laboratory-scale study, the use of UV-A and a special TiO₂-based photocatalyst reduced concentrations of several important air pollutants (NH₃, CO₂, N₂O, O₃) without impact on H₂S & CH₄. Therefore, this research's objectives were to (1) scale-up of the UV treatment to pilot-scale, (2) evaluate the mitigation of odor and odorous VOCs. The effects of a photocatalyst's presence (photocatalysis & photolysis), UV intensity (LED & fluorescent), and treatment time we studied in the pilot-scale experiments inside a poultry barn. The results of pilot-scale experiments were consistent with the lab-scale: the % reduction under photocatalysis was generally higher than photolysis. In addition, the % reduction of target gases at a high light intensity and long treatment time was higher. The % reduction of NH₃ was 5~9%. There was no impact on H₂S, CH₄, and CO₂ under any experimental conditions. N₂O & O₃ concentrations were reduced at 6~12% & 87~100% by both photolysis & photocatalysis. In addition, concentrations of several VOCs responsible for livestock odor were reduced from 26~62% and increased with treatment time & light intensity. The odor was reduced by 18%. Photolysis treatment reduced concentrations of N₂O, VOCs, and O₃, only. Further scale-up and research at the farm-scale are warranted.*

Keywords. Air pollution, odor, indoor air quality, emissions, poultry production, photocatalysis.

Introductions

Poultry farmers are producing eggs, meat, and feathers with increasing efficiency and a lower carbon footprint. Technologies to address concerns about the air quality inside barns and the gaseous emissions from farms to the atmosphere continue to be among industry priorities. Only ~25% of research on technologies to mitigate emissions from animal production systems has been tested on farms, and scaling up technologies from the lab- to farm-scales has proven to be a challenge. However, farmers prefer technologies that are simple to adopt and low in cost. Therefore, pilot- and farm-scale experiments should be preceded for the technical application on the livestock farm. According to previous studies (Maurer et al., 2016), the treatment of odorous emissions with UV light has the potential to be a relatively simple adaptation to existing and new facilities. Yet, many practical questions remain to be addressed to scale up this technology from the lab to the farm.

Proposed UV-based methods consist of direct irradiation and photocatalytic treatment. In the former, light is directly absorbed by the target gases (or potentially other photoreactive gases). By contrast, photocatalysis consists of the light being principally absorbed by a photoactive coating with secondary reactions between target gases and reactive intermediates taking place mainly at or near the coated surfaces. UV irradiation treatment has a variety of mitigation effects on the target gas, depending on several parameters. Direct irradiation generally requires shorter wavelength light (e.g., 254 nm), in that few target molecules absorb in the near UV (e.g., 360 nm), whereas photocatalytic treatment can proceed with the longer wavelengths because of choice of coating. Light flux is another obvious parameter. Other critical variables in the real application are the presence of other agents in the gas mixture, such as the degree of humidity and the presence or absence of ozone.

The wavelength of irradiation is an important consideration for the application of UV technology because of its potential effects on humans and animals. The very shortest, easily accessible wavelengths (e.g., 185 nm) will cause a buildup of ozone and N_2O because the light is absorbed by atmospheric O_2. Traditional bactericidal light sources (often 254 nm) do not cause that problem but would cause rapid sunburn for exposed skin. Near-UV light (often called UV-A) that is sufficient for photocatalysis is also not appropriate for long-term skin exposure but is otherwise the most benign. The most common photocatalyst is nano-particulate TiO_2, which is chosen for its relatively broad application, comparatively high efficiency, durability, lack of toxicity, and low cost (Hashimoto et al., 2005; Zaleska, 2008; Rockafellow et al., 2012; Schneider et al., 2014).

Photocatalysis is initiated when photons of sufficient energy (i.e., greater than the semiconductor bandgap) are absorbed by the TiO_2 particles, resulting in electron/hole (e-/h+) generation (Vautier et al., 2001; Schneider et al., 2014; Lee et al., 2018; Maurer and Koziel, 2019). For commonly available TiO_2, the threshold is roughly 380 nm. Under atmospheric moisture conditions, HO• (hydroxyl) radicals are produced by the interaction of hole (h+) with H_2O molecular (Vautier et al., 2001; Nakata and Fujishima, 2012; Lee et al., 2018; Maurer and Koziel, 2019). The most common electron sink is molecular oxygen. Either through these reactive intermediates or by direct interaction with the e- or h+, the target materials are degraded. Full mineralization (conversion to CO_2, H_2O, and inorganic ions) can usually be achieved through exhaustive treatment. Although the detailed mechanism of photocatalysis varies with different target pollutants and treatment conditions, it is commonly agreed that the primary reactions responsible are these interfacial oxidation and reduction reactions (Abe, 2010; Maeda and Domen, 2010; Nakata and Fujishima, 2012; Schneider et al., 2014).

The applicability of UV photocatalytic technology to the farm has been investigated in previous studies. Photocatalysis based on TiO_2 has been evaluated to reduce odorous gases and fine particulate concentrations as well as for increased feed conversion rates (Guarino et al., 2008; Costa et al., 2012; Zhu et al., 2017; Maurer and Koziel, 2019). In addition, optimal conditions and parameters affecting target gas mitigation have been investigated (Lee et al., 2020). Moreover, economic analysis has shown that it is reasonable compared to other technologies (Koziel et al., 2008; Liu et al., 2015).

Here we report a study of the mitigation of odorous target gases, VOCs, GHGs, and odor using UV-A treatment in actual poultry farms. This study was brought up to a pilot-scale based on the lessons learned about UV-A performance of the photocatalysis demonstrated in a recent lab-scale study (Lee et al., 2020a). The results provided evidence that photocatalysis with TiO_2 coating and UV-A light can reduce gas concentrations of NH_3 (3~19%), CO_2 (4%), N_2O (7~12%), and O_3 (12~48%) without significant effect on H_2S and CH_4. In addition, the mitigation of target gases was generally improved with parameters that sensibly dictate higher effective dosages: the presence of photocatalyst, relative humidity (RH, 12%), higher light intensity, longer treatment time, and low dust accumulation on the photocatalyst surface. However, it was found that the optimum mitigation conditions (RH and dust accumulation) and the effect of parameters (light intensity and treatment time) depend on the type of targeted gas.

Poultry barns manage lighting very precisely due to bird physiological and production needs. Thus, the poultry industry is generally prepared to consider the adoption of light-based technologies. However, carefully scaled-up studies are still needed to move forward with UV-based treatment for air quality improvements without jeopardizing current production practices. To date, no studies report on applying actual photocatalysis technology in real poultry farms. Therefore, the objectives of this research are (1) to scale-up the UV treatment to pilot-scale in the poultry farm and (2) to evaluate the mitigation of NH_3, H_2S, GHGs, odor, and odorous VOCs. In addition, the effects of photocatalyst presence (in comparison to direct photolysis), UV intensity (based on LED vs. fluorescent light sources), and treatment time were studied in the pilot-

scale experiments inside a poultry barn.

Materials and Methods

Experimental reactor setup

The reactor (2.44 x 0.3 x 0.3 m) was designed with reference to previous research (Maurer and Koziel, 2019) as shown in the system illustrated in Lee et al., 2020b; Figure 1. The frame consisted of a plated steel slotted angle (Lowes, Mooresville, NC, USA) with an embossed white fiberglass reinforced plastic wall panel (Lowes, Mooresville, NC, USA). The frame was constructed to support interchangeable wall panels (0.3 x 0.61 x 0.002 m, regular panel vs. TiO2 coated panel). These materials are commonly used as an interior wall in a livestock barn (Maurer and Koziel, 2019). The wall panel's bottom was coated with a photocatalyst (nanostructured anatase TiO_2 at 10 µg·cm^{-2} from PureTi, Cincinnati, OH, USA). All of the wall panels are changed when testing the effect of photocatalysis from uncoated panels to coated ones. On the front and back panels, a 0.1 m diameter hole was made to allow airflow in the reactor. The reactor air inlet consisted of two duct reducers with a diameter of 0.20 m to 0.15 m and a diameter of 0.15 m to 0.10 m (Lowes, Mooresville, NC, USA).

A fan was installed in a 0.1 m diameter steel axial duct (Lowes, Mooresville, NC, USA) at the end of the reactor. The fan drew air from the inlet of the reactor to the outlet. The fans were able to adjust the flow rate using the dimmer switch. Therefore, the fan velocity calibration was conducted to adjust the flow rate in the reactor.

The reactor was illuminated with two fluorescents (Spectroline, Westbury, NY, USA) and one LED (ONCE, Plymouth, MN, USA). Both sources emit predominantly at 365 nm. Two fluorescent UV lamps were installed in the middle and 0.15 m behind the center lamp. For the LED-based treatment, one UV lamp was installed in the middle of the reaction.

Measurement of ammonia (NH_3) and hydrogen sulfide (H_2S) concentrations, temperature, relative humidity (RH), and ozone (O_3) were conducted in real-time. Temperature and RH were monitored via an 850071 Environmental Quality meter (Sper Scientific, Scottsdale, AZ, USA). Gas samples for Greenhouse gases (GHGs), odorous volatile organic compounds (VOCs), and odor were collected and subsequently analyzed in the lab. Samples were collected at the reducer at the front of the reactor and 0.15 m away from the rear board. The measurement of target gases was triplicated.

TiO₂ coating

TiO$_2$ coating was conducted with the spraying method. TiO$_2$ coating on the panel was carried out by a professional protocol provided by PureTi company(Cincinnati, OH, USA). In addition, spray training was conducted with SATA help (Spring Valley, MN, USA) for accurate spraying control. Before starting the coating, the temperature (25 °C) and relative humidity (40-45%) of the site were adjusted to prevent instant evaporation of the sprayed TiO$_2$ solution (nanostructured anatase 10 µg TiO$_2$, PureTi, Cincinnati, OH, USA). Then, after cleaning the surface of the experiment panel, TiO$_2$ solution was sprayed. When spraying, the pressure was adjusted to 60 psi with a regulator from the compressor, and the distance between the panel and the spray was 6 inches, and the angle was 90 degrees. And after 3 days, the coated panel was used for the experiment.

Experimental fan calibration

The fan calibration was performed by measuring the velocity of each 0.012 m distance triplicated from the top of the fan and averaging a total of 8 points air velocity (illustrated in Lee et al., 2020; Table 1). The dimmer switch was adjusted to measure the maximum, medium, and minimum air velocity of the pan. These three velocities were named as setting 1, 2, and 3 from the fastest speed order. In the experiments, fan velocity used settings 2.0, 2.5, and 3.0 to set typical air exchange rates inside mechanically-ventilated barns. The treatment times in the inside of the reactor corresponding to the three air velocities are 40, 100, and 170 s, respectively. The air velocity of the fan was measured using a wind speed sensor (Modern Device, Providence, RI, USA) with Arduino Uno (Arduino LLC, Boston, MA, USA). The wind sensor was calibrated using the value of volts from the sensor at the WTM-1000 mini wind tunnel (Omega Engineering Inc., Norwalk, CT, USA) from 0 to 10 m·s^{-1} (illustrated in Lee et al., 2020b; Figure 2).

UV-A light sources

Two fluorescent light bulbs were combined with one lamp, and a total of two lamps were used in this study. The LED used an aluminum board equipped with 108 LED chips. Light intensity was measured with an ILT-1700 radiometer (International Light Technologies, Peabody, MA, USA) equipped with an NS365 filter and SED033 detector (International Light Technologies, Peabody, MA, USA). For economic analysis, power consumption was measured using a wattage meter (P3, Lexington, NY, USA). The LED had ~10x greater intensity and lower power consumption compared with the fluorescent lamp (Table1). The effective exposure of light intensity was mapped on the reactor's interior surfaces (illustrated in Lee et al., 2020b; Figure 3).

Table 1. Comparison of experimental UV-A lamps.

	Fluorescent	LED
Total light intensity (mW·cm^{-2})	0.44	4.85
Power (W)	48.2	43.3

Teaching poultry farm

Pilot-scale testing was conducted at ISU Poultry Teaching Farm (Ames, IA, USA). The study was not using animals, and they were not exposed to UV-A. The performance of UV-A reactor was tested in realistic barn conditions where the environmental parameters (temperature, relative humidity, ventilation), dust, gases were representative of the conditions inside poultry barns in general. The teaching farm is a caged facility with about 200 laying hens. Animal density is 0.045-0.056 m^3 head^{-1}. Once a day, the manure was cleaned manually using a scraper. The teaching farm was set up with a side ventilation system in which the flow rate of the fan was automatically changed according to the temperature. The UV-A reactor was located in a nearby manure collector site (illustrated in Lee et al., 2020; Figure 4).

Ammonia and hydrogen sulfide

A gas monitoring system (OMS-300, Smart Control & Sensing Inc., Daejeon, Rep. of Korea) equipped with electrochemical gas sensors of Membrapor Co. (Wallisellen, Switzerland) was used to measure NH_3 (NH3/CR-200) and H_2S (H2S/C-50) concentrations. Both gas sensors were calibrated with standard gases before the experiment. The calibration result of both sensors was $R^2 > 0.98$.

Volatile organic compounds

Samples were collected and analyzed in the same method as in the previous study (Maurer and Koziel, 2019). Air samples for VOC measurements were collected using 1 L glass gas sampling bulbs (Supelco, Bellefonte, PA, USA). Air samples were taken using a portable vacuum sampling pump (Leland Legacy; SKC Inc., Eighty-Four, PA, USA) with a set flow rate of 5 L min^{-1} for 1 min and analyzed in the same day. Chemical analyses of poultry odorants were completed using a solid-phase microextraction (SPME) (50/30 µm DVB/CAR/PDMS; 2 cm-long fibers, Supelco, Bellefonte, PA, USA) using static extraction for 1 h at room temperature and gas chromatography-mass spectrometry (GC-MS) system for analyses (Agilent 6890 GC; Microanalytics, Round Rock, TX, USA).

Greenhouse gases

Methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) measured in this study as the greenhouse gases (GHGs). GHGs samples were collected using syringes and 5.9 mL Exetainer vials (Labco Limited, UK) and were analyzed for GHG concentrations on a GC equipped with FID and ECD detectors (SRI Instruments, Torrance, CA, USA). Samples were analyzed on the day of collection. Standard calibrations were constructed daily using 10.3 ppm and 20.5 ppm CH_4; 1005 ppm and 4010 ppm CO_2; and 0.101 ppm and 1.01 ppm N_2O; and pure helium used to 0 ppm (Air Liquide America, Plumsteadville, PA, USA).

Ozone

The O_3 detector was connected to the monitoring system (Series 500 monitor, Aeroqual, New Zealand) and installed at the sampling site inside the reactor. The ozone sensor (OZS, Aeroqual, New Zealand) was sent to the professional company (Gas Sensing, IA, USA) for certified calibration before use. The detection range was from 0 to 50 ppb.

Odor

Odor samples were collected from the incoming and outgoing air sampling ports of the UV reactor in 10 L Tedlar sample bags using a Vac-U-Chamber (SKC Inc., Eighty-Four, PA, USA) and sampling pump (SKC Inc., Eighty-Four, PA, USA). Tedlar sampling bags were pre-cleaned by flushing with clean air three times before use. Odor samples were analyzed using a dynamic triangular forced-choice olfactometer (St. Croix Sensory Inc., Stillwater, MN, USA). Four trained panelists at two repetitions each were used in the analysis of each sample. Each sample was presented to the panelists from low concentration to higher concentrations; each dilution level doubled the concentration of the odor.

Data measurement and analysis

Gas samples were collected after 30 min of equilibration time under each treatment condition. The overall mean % reduction (mitigation) for each measured gas was estimated using:

$$\% \ Reduction = \frac{E_{con} - E_{Treat}}{E_{con}} \times 100 \tag{1}$$

where

E_{Con} and E_{Treat} = the mean measured concentrations in control and treated air, respectively

Emission rates were calculated as a product of measured gas concentrations and the total airflow rate through the wind tunnel, adjusted for standard conditions and dry air using collected environmental data. The overall mean mitigation of each measured gas emission was estimated using:

$$Mitigation\ of\ emission = \left(C_{con} \times V \times \frac{273.15 \times MW}{(K_{Con}) \times 2.24 \times 10^4} - C_{Treat} \times V \times \frac{273.15 \times MW}{(K_{Treat}) \times 2.24 \times 10^4}\right) \qquad (2)$$

Where:

Mitigation of emission (g min^{-1}) = the mitigation of gas emission

C_{Con} and C_{Treat} = the mean measured concentrations in control and treated air (mL m^{-3}), respectively

V = the ventilation rate (m^3 min^{-1})

MW = the molecular weight of target gas (g mol^{-1})

K_{Con} and K_{Treat} = the temperature in control and treated air (K), respectively

2.24 x 10^4 = an ideal gas conversion factor for liters to moles at 273.15 K.

Statistical analysis

The program of R (version 3.6.2) was used to analyze the mitigation effect of UV-A irradiative treatment for target gases on the poultry farm. The parameters of catalyst, lamp-type, and treatment time between control concentration and treatment concentration were statistically analyzed using one-way ANOVA. The statistical difference was confirmed by obtaining the p-value through the paired Tukey test. A significant difference was defined for a p-value <0.05 in this study.

Results

Environmental parameters

The average temperature inside the poultry barn was 25±3 °C, and the average RH was 59±4 %. The average temperature of the gas after the fluorescent UV-A light irradiation and LED was 27±2 and 28±3°C, respectively. In addition, RH decreased by about 3% after UV irradiation. Therefore, after the UV-A light irradiation, the temperature was increased, but RH was decreased. It was confirmed that the concentration of target gases was significantly reduced because of the increased ventilation in the farm from 12:00 PM (e.g., NH3 concentration is 10±1 ppm at 12 PM). Therefore, all samples were collected before 10 AM.

Ammonia and Hydrogen sulfide

The average NH_3 concentration in the poultry barn without treatment was 23±3 ppm. In the case of photolysis, there was no statistically significant NH_3 mitigation in all experimental conditions (p>0.05). For photocatalysis, the % NH_3 reduction was 5% when using fluorescent UV-A and 9% when using LED UV-A (p<0.05). The H_2S concentrations were too low for measurement with the instrumentation used (0~5 ppb). Thus, reductions could not be estimated (illustrated in Lee et al., 2020b; Table 3).

Volatile organic compounds

In the case of photolysis, three VOCs showed statistically significant % reductions and were limited to the longest treatment time (170 s), i.e., dimethyl disulfide (25.8% under fluorescent UV-A), p-cresol (35.6%) & indole (31.4%) under LED UV-A. In the case of photocatalysis, five VOCs showed significant % reductions, i.e., p-cresol (32.2% under fluorescent UV-A), and dimethyl disulfide, butanoic acid, p-cresol, indole, and skatole showed 31.2~61.9% reductions under LED UV-A. In general, treatment with the LED at the longest treatment time (170 s) was most effective in reducing the concentrations of most VOCs measured (illustrated in Lee et al., 2020b; Table 4).

Greenhouse gases

The average GHGs concentration in the poultry barn was 2.5±0.2 (CH_4), 465±48 (CO_2), and 0.28±0.03 (N_2O) ppm. For CH_4 and CO_2, there was no statistically different change in their concentration. However, N_2O showed under photocatalysis an average 6% reduction with fluorescent UV-A and 9% with LED UV-A. In addition, The photolysis using only an LED UV light source still showed a 7% reduction. The N_2O mitigation showed a significantly higher % reduction with the high light intensity and with a longer treatment time (illustrated in Lee et al., 2020b; Table 5).

Odor

Odor % reduction was statistically different only in long treatment time and high light intensity conditions (LED, 170 s). The odor % reduction was presented at 18% (p<0.05). The odor unit (OU$_e$·m^{-3}) decreased from 582±25 to 475±38 in

condition with statistical differences (illustrated in Lee et al., 2020b; Table 6).

Ozone

The average O_3 concentration in control samples was 9.0±4.7 ppb. The average O_3 concentration after treatments was 0.3±1.2 (ppb). Both photolysis and photocatalysis showed a similar tendency to decrease O_3 concentration (illustrated in Lee et al., 2020b; Table 7). The LED-based irradiations showed a greater reduction than fluorescent (100% vs. 87%). However, there was no statistically significant difference between them (p>0.05).

Discussion

This pilot-scale study showed the % reduction in the concentrations of NH_3, N_2O, O_3, and some types of VOCs in poultry barn exhaust as a result of direct and indirect photolytic treatment. The results show similar trends as the laboratory experiment that used the same UV-A light source and TiO_2 density. A comparison of the laboratory and pilot scales are summarized in Table 8 (Lee et al., 2020b). On the laboratory scale (Lee et al., 2020a), an RH of 12% was reported as the optimal humidity condition for reducing target gases. As the treatment time decreased, the light intensity decreased, the relative humidity increased, and dust accumulation increased, the % reduction gradually decreased. As a representative example, when the RH increased from 12% to 60%, the % reduction of NH_3 declined from 19% to 6%. Therefore, the mitigation for the target gas was expected to be low, considering the actual RH and dust inside the poultry farm.

However, unlike these concerns, there was a statistically significant decrease in NH_3, N_2O, and O_3. In the case of NH_3 concentration, the % reduction increased with the increase of the light intensity. However, it did not show a statistical difference with the treatment time (100 s vs. 170 s). For N_2O concentration, the % reduction improved as the light intensity and the treatment time increased. O_3 was detected in very low concentrations in the poultry farm; then, it was almost mitigated after UV irradiation. Interestingly, CO_2 did not show a % reduction effect, which is a different result compared with that from the lab-scale. It is considered a result reflecting that there is no chemical reason for reducing CO_2 under general photocatalysis conditions with normal TiO_2. Pilot studies also showed that photocatalysis has the effect of improving indoor air quality by reducing some types of VOC and odor. Therefore, the application of photocatalysis in the poultry farm through lab-scale and pilot-scale results is considered to be a potential and positive technology in terms of reducing odorous gases, decreasing GHGs, and improving indoor air quality.

Conclusion

The results of the study provide evidence that a photocatalyst using TiO_2 coating and UV-A light can reduce the target gas concentrations in poultry farm conditions. The photocatalysis reduced NH_3, N_2O, O_3, VOCs, and odor. However, it did not affect H_2S, CH_4, and CO_2. In the case of NH_3 concentration, the % reduction ranged from 5 to 9% and was affected by light intensity. However, there was no statistical increase with increasing treatment time. The % reduction in N_2O and O_3 concentrations increased with increasing light intensity and treatment time (6~12% for N_2O and 87~100% for O_3). For VOCs, greater light intensity (LED) and longer treatment time (170 s) improved mitigation. The % reduction was observed for DEDS (26-47%), BA (62%), p-cresol (32-49%), indole (31%), and skatole (35%) concentrations. The odor showed a statistical reduction of 18% only under LED with170 s treatment time. The application of photocatalysis based on TiO_2 with UV-A in the poultry farm is therefore considered to be beneficial in terms of reducing odorous gases, decreasing GHGs, removing O_3, and improving indoor air quality. Further research needs to be extended to farm-scale trials for investigating more detailed economic analysis and mitigation of target gases. In addition, it is also necessary to investigate the by-products after photocatalysis treatment for safe technology applications.

and Hoa-Thanh Huynh from ONCE Innovations for the LED array and Bikash Rajkarnikar (PureTi) for coating with a photocatalyst.

References

Abe, R. (2010). Recent progress on photocatalytic and photoelectrochemical water splitting under visible light irradiation. *Journal of Photochemistry and Photobiology C: Photochemistry Reviews, 11*(4), 179-209. doi:10.1016/j.jphotochemrev.2011.02.003

Costa, A., Chiarello, G. L., Selli, E., & Guarino, M. (2012). Effects of TiO_2 based photocatalytic paint on concentrations and emissions of pollutants and on animal performance in a swine weaning unit. *Journal of Environmental Management, 96*(1), 86-90.

Guarino, M., Costa, A., & Porro, M. (2008). Photocatalytic TiO_2 coating—To reduce ammonia and greenhouse gases concentration and emission from animal husbandries. *Bioresource Technology, 99*(7), 2650-2658.

Hashimoto, K., Irie, H., & Fujishima, A. (2005). TiO_2 photocatalysis: a historical overview and future prospects. *Japanese Journal of Applied Physics, 44*(12R), 8269.

Koziel, J., Yang, X., Cutler, T., Zhang, S., Zimmerman, J., Hoff, S., . . . Armon, R. (2008). *Mitigation of odor and pathogens from CAFOs with UV/TiO₂: Exploring the cost effectiveness.* Paper presented at the Proc. Mitigating Air Emissions from Animal Feeding Operations. Conference Proceedings, Des Moines, IA. Iowa State University.

Lee, H. J., Park, Y. G., Lee, S. H., & Park, J. H. (2018). Photocatalytic Properties of TiO_2 According to Manufacturing Method. *Korean Chemical Engineering Research, 56*(2), 156-161. doi:10.9713/kcer.2018.56.2.156

Lee, M., Wi, J., Koziel, J. A., Ahn, H., Li, P., Chen, B., . . . Jenks, W. (2020a). Effects of UV-A Light Treatment on Ammonia, hydrogen sulfide, greenhouse gases, and ozone in simulated poultry barn conditions. *Atmosphere, 11*(3), 283.

Lee, M., Li, P., Koziel, J. A., Ahn, H., Wi, J., Chen, B., ... & Jenks, W. S. (2020b). Pilot-scale testing of UV-A light treatment for mitigation of NH_3, H_2S, GHGs, VOCs, odor, and O_3 inside the poultry barn. *Frontiers in Chemistry, 8*, 613, doi.org/10.3389/fchem.2020.00613.

Liu, Z., Murphy, P., Maghirang, R., & DeRouchey, J. (2015). *Mitigation of air emissions from swine buildings through the photocatalytic technology using UV/TiO₂.* Paper presented at the 2015 ASABE Annual International Meeting.

Maeda, K., & Domen, K. (2010). Photocatalytic water splitting: recent progress and future challenges. *The Journal of Physical Chemistry Letters, 1*(18), 2655-2661. doi:10.1021/jz1007966

Maurer, D. L., & Koziel, J. A. (2019). On-farm pilot-scale testing of black ultraviolet light and photocatalytic coating for mitigation of odor, odorous VOCs, and greenhouse gases. *Chemosphere, 221*, 778-784.

Maurer, D. L., Koziel, J. A., Harmon, J. D., Hoff, S. J., Rieck-Hinz, A. M., & Andersen, D. S. (2016). Summary of performance data for technologies to control gaseous, odor, and particulate emissions from livestock operations: Air management practices assessment tool (AMPAT). *Data in Brief, 7*, 1413-1429. doi:10.1016/j.dib.2016.03.070

Nakata, K., & Fujishima, A. (2012). TiO_2 photocatalysis: Design and applications. *Journal of Photochemistry and Photobiology C: Photochemistry Reviews, 13*(3), 169-189. doi:10.1016/j.jphotochemrev.2012.06.001

Rockafellow, E. M., Koziel, J. A., & Jenks, W. S. (2012). Laboratory-scale investigation of UV treatment of ammonia for livestock and poultry barn exhaust applications. *Journal of Environmental Quality, 41*(1), 281-288.

Schneider, J., Matsuoka, M., Takeuchi, M., Zhang, J., Horiuchi, Y., Anpo, M., & Bahnemann, D. W. (2014). Understanding TiO_2 photocatalysis: mechanisms and materials. *Chemical Reviews, 114*(19), 9919-9986.

Vautier, M., Guillard, C., & Herrmann, J.-M. (2001). Photocatalytic degradation of dyes in water: case study of indigo and of indigo carmine. *Journal of Catalysis, 201*(1), 46-59. doi:10.1006/jcat.2001.3232

Zaleska, A. (2008). Doped-TiO_2: a review. *Recent Patents on Engineering, 2*(3), 157-164.

Zhu, W., Koziel, J., & Maurer, D. (2017). Mitigation of livestock odors using black light and a new titanium dioxide-based catalyst: Proof-of-concept. *Atmosphere, 8*(6), 103. doi:10.3390/atmos8060103