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Ammonia, hydrogen sulfide, carbon dioxide and particulate matter emissions from California high-rise layer houses

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ABSTRACT

Ammonia and hydrogen sulfide are hazardous substances that are regulated by the U.S. Environmental Protection Agency through community right-to-know legislation (EPCRA, EPA, 2011). The emissions of ammonia and hydrogen sulfide from large commercial layer facilities are of concern to legislators and nearby neighbors. Particulate matter (PM_{10} and $PM_{2.5}$) released from layer houses are two of seven criteria pollutants for which EPA has set National Ambient Air Quality Standards as required by the Clean Air Act. Therefore, it is important to quantify the baseline emissions of these pollutants. The emissions of ammonia, hydrogen sulfide, carbon dioxide and PM from two California high-rise layer houses were monitored for two years from October 2007 to October 2009. Each house had 32,500 caged laying hens. The monitoring site was setup in compliance with a U.S. EPA-approved quality assurance project plan. The results showed the average daily mean emission rates of ammonia, hydrogen sulfide and carbon dioxide were 0.95 ± 0.67 (standard deviation) g d^{-1} $bird^{-1}$, 1.27 ± 0.78 mg d^{-1} $bird^{-1}$ and 91.4 ± 16.5 g d^{-1} $bird^{-1}$, respectively. The average daily mean emission rates of $PM_{2.5}$, PM_{10} and total suspended particulate (TSP) were 5.9 ± 12.6, 33.4 ± 27.4, and 78.0 ± 42.7 mg d^{-1} $bird^{-1}$, respectively. It was observed that ammonia emission rates in summer were lower than in winter because the high airflow stabilized the manure by drying it. The reductions due to lower moisture content were greater than the increases due to higher temperature. However, PM_{10} emission rates in summer were higher than in winter because the drier conditions coupled with higher internal air velocities increased PM_{10} release from feathers, feed and manure.

1. Introduction

Large-scale egg-production facilities are emission sources of various gases and particulate matter (PM). Ammonia (NH_3) is one of the main gases emitted from laying hen houses. Atmospheric NH_3 can be a precursor of secondary fine PM and can significantly enhance acid rain (Xin et al., 2011). The PM is generally classified as total suspended particulate (TSP), PM_{10} with an aerodynamic diameter of 10 μm or less, and $PM_{2.5}$ or fine PM with an aerodynamic diameter of 2.5 μm or less. The fine PM can be inhaled and deposited in the human lung and causes respiratory infection and increases risk for asthma, vascular inflammation, lung cancer and heart disease (Pope et al., 2002, and Gilmour et al., 2006). Ammonia and hydrogen sulfide (H_2S) are classified as hazardous substances under EPCRA (EPA, 2011), and PM_{10} and $PM_{2.5}$ are two criteria pollutants for which EPA has set National Ambient Air Quality Standards as required by the Clean Air Act. The emissions from layer housing have been reported previously (Gay et al., 2003; National Research Council, 2003; Nicholson et al., 2004; Liang et al., 2005; Ni et al., 2009). However, there is a need for obtaining more emission data from commercial farm operations, especially to determine the ranges and dynamics of emission rates (ER) under different environmental conditions, housing conditions, feeding and manure management practices. No layer data from California had yet been obtained. To address this important need, the National Air Emission Measurement Study (NAEMS) was carried out by a team of university scientists and engineers to monitor the concentrations of selected gases and PM from 24 livestock and poultry production facilities and manure storage areas for two years.

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One of these monitoring sites was a layer facility in California, which served as a representation of western egg-production in high-rise houses. The monitoring site setup, started in June 2007, followed a Quality Assurance Project Plan (QAPP), which included a site monitoring plan and standard operating procedures (Heber et al., 2007). The data collection was started in October 2007 and finished in October 2009. The concentrations of NH_3, H_2S, carbon dioxide (CO_2) and PM ($PM_{2.5}$, PM_{10}, and TSP) at several locations in the houses and the exhaust airflow rates were continuously measured, and ERs were calculated. The objectives of this paper are to report the measurement results and analyze the influence of several factors on the ERs.

2. Methodologies

2.1. Monitoring site characteristics

At a four-barn layer ranch in California, one barn (144 m long, 15 m wide, 6.7 m high sidewalls, and 9.1 m high ridge) was selected as the monitoring site. The building was completely separated by a middle wall into two distinct houses (7.5 m wide), referred to as House 5 (H5) and House 6 (H6). Houses 5 and 6 were high-rise and identical in building design, feeding, manure management, and ventilation. Each house contained approximately 32,500 hens in two rows of five-tier cages in the second (upper) floor. The flock had a 16-month service period, and the average mass per bird was 1.68 kg with an average feed consumption of 111 ± 17 (SD) g d^{-1} $bird^{-1}$. There was one molting period for each flock of layers during which the feed consumption was 60% of normal.

Each house had two floors. Ventilation air entered the second or upper floor of each house through an air inlet under the eave, and then was exhausted through ten 122-cm fans (AT481Z1, Aerotech, Mason, MI) and two 91-cm fans (AT36Z1, Aerotech, Mason, MI) installed in the sidewall on the first floor. The fan operation was controlled by the second floor temperature in nine stages. Manure was scraped off dropping boards under the cages into the first floor, where it was stored for six months prior to removal. Manure was removed from H5 on 10/17/07, 3/4/08, 5/22/08, 6/7/08, 8/22/08, 2/10/09 and 8/21/09, and from H6 on 10/17/07, 3/6/08, 8/21/08, 2/10/09 and 8/21/09. The layers were removed from H5 on 6/7/08 and from H6 on 8/21/08.

2.2. Monitoring method

Lin et al. (2009) described the measurement variables and methods used at this site. In all, 110 variables were measured continuously (Table 1). Manure, feed, egg, and water samples were collected eight, two and two times from each house, respectively, and water samples were collected once. The nitrogen content of these samples was measured by a certified independent laboratory for further nitrogen balance analysis. Fig. 1 shows the plan-view and end-wall view of H5 and H6, and the relative locations of measurement sensors and instruments. The environmentally-controlled on-farm instrument shelter (OFIS) was situated west of H6 between fans 6 and 7 (Fig. 1) to house the data acquisition and gas sampling systems.

Table 1
Continuously-monitored variables (Lin et al., 2009).

Type	Measured variables
Gas concentration	Ammonia (NH_3), carbon dioxide (CO_2), hydrogen sulfide (H_2S) and sulfur dioxide (SO_2)
Particulate matter (PM) concentration	PM ≤ 10 μm (PM_{10}), ≤2.5 μm ($PM_{2.5}$) and total suspended particulate (TSP)
Ventilation	Fan rotational speed, differential pressure and airflow
Environment	Temperature, relative humidity, wind speed and direction, and solar radiation
Operation relays	Light, scraper, mister and inlet operation
Activity	Bird activity and worker movement in houses
Gas sampling system operation	Temperature, relative humidity, flow rate/direction and pressure of sampled air

The gas sampling system (GSS) sequentially sampled the air at six in-house locations (three per house) plus one inlet location on the west sidewall under the eave, and delivered the samples to the gas analyzers. The GSS had two pumps and the main pump drew sample air at approximately 4.2 L min^{-1}, while the bypass pump (P1) purged the six inactive sampling lines with a combined flow rate of approximately 7.2 L min^{-1} (1.2 L min^{-1} $line^{-1}$). AirDAC (Air Data Acquisition and Control Software; Ni and Heber, 2010) controlled the solenoid operation, and thus the sampling frequency for each line. The GSS sampled the inlet air for 30 min, and then repeatedly (11 times) sequenced through each of the six exhaust air sampling probes in H5 and H6 for 10 min each. Therefore, each in-house sampling location was processed 22 times and the inlet sampling location was sampled twice every 23 h. Two 1-μm filters were installed in a sampling line composed of Teflon tubing (OD 3/8" and ID 1/4") to prevent dust from entering the tube. The GSS operational parameters of flow rate, relative humidity, temperature, and pressure were monitored by a flowmeter (Model 50S-10S4, McMillan Company, Georgetown, TX), a relative humidity and temperature transducer (Model HMP50YCB2A1X, Vaisala, Woburn, MA) and a pressure sensor (Model 2301002PD2F11B, Setra, Boxborough, MA), respectively. The gas sampling tubes were heated and insulated to prevent condensation in the sampling lines.

A photoacoustic IR multi-gas monitor (INNOVA Model 1412, Lumasence, Ballerup, Denmark) was used to measure NH_3 and CO_2 concentrations. A fluorescence-based H_2S analyzer (Model 450i, Thermo Environmental Instruments, Franklin, MA) was used to measure H_2S concentrations.

A Beta Gage (Model FH62 C-14, Thermo Environmental Instruments, Franklin, MA) was installed in the OFIS with its sampling inlet extending through and 1.5 m above the roof of the OFIS to measure inlet PM concentrations. A tapered element oscillating microbalance (TEOM Model 1400a, Thermo Environmental Instruments, Franklin, MA) was located immediately upstream of fan 6 in both H5 and H6 (Fig. 1) to measure the exhaust PM concentrations. The PM_{10}, $PM_{2.5}$ and TSP were measured by alternating the PM_{10}, $PM_{2.5}$ and TSP inlets of both TEOMs and the Beta gage. The PM_{10}, PM2.5 and TSP were monitored for 518 d over 11 separate monitoring runs, 49.5 d over three periods and 53 d over seven periods, respectively.

Two activity sensors (VS-SRN2000N, Visonic, Tel Aviv, Israel) monitored the relative activity of the birds in the two rows of cages within each house. Relative humidity and temperature probes (RHT-WM, NOVUS, Sao Paulo, Brazil) were installed near fan 6 in each house (Fig. 1), and within an empty cage on the second floor. Thermocouples (Type T, TE Wire and Cable, Saddle Brook, NJ) were used to measure the temperatures near the inlets to fans 2 and 10 in both H5 and H6. A pyranometer (LI-200SL, LiCor, Lincoln, NE) to measure solar radiation, a shielded RH/temperature probe (RHT-WM) to measure ambient temperature and relative humidity, and a wind anemometer (Wind Sentry 03002VM, RM Young Company, Traverse City, MI) to measure wind speed and direction were installed on a 1.5-m weather tower mounted on the ridge of two houses.