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Assessment of particulate matter and ammonia emission concentrations and respective plume profiles from a commercial poultry house☆

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ABSTRACT

Poultry-emitted air pollutants, including particulate matter (PM) and ammonia, have raised concerns due to potential negative effects on human health and the environment. However, developing and optimizing remediation technologies requires a better understanding of air pollutant concentrations, the emission plumes, and the relationships between the pollutants. Therefore, we conducted ten field experiments to characterize PM (total suspended particulate [TSP], particulate matter less than 10 μm in aerodynamic diameter [PM_{10}], and particulate matter less than 2.5 μm in aerodynamic diameter [$PM_{2.5}$]) and ammonia emission-concentration profiles from a typical commercial poultry house. The emission factors of the poultry house, which were calculated using the concentrations and fan speed, were 0.66 (0.29–0.99) g NH_3-N $bird^{-1}d^{-1}$ for ammonia, 52 (44–168) g $d^{-1}AU^{-1}$ (AU = animal unit = 500 kg) for TSP, 3.48 (1.16–9.03) g $d^{-1}AU^{-1}$ for PM_{10}, and 0.07 (0.00–0.36) g $d^{-1}AU^{-1}$ for $PM_{2.5}$. PM and ammonia emission concentrations decreased as distance from the fan increased. Although emission concentrations were similar in the daytime and nighttime, diurnal and nocturnal plume shapes were different due to the increased stability of the atmosphere at night. Particle size distribution analysis revealed that, at a given height, the percentage of PM_{10} and $PM_{2.5}$ was consistent throughout the plume, indicating that the larger particles were not settling out of the airstream faster than the smaller particles. Overall, the direction of the measured air pollutant emission plumes was dominated by the tunnel fan ventilation airflow rate and direction instead of the ambient wind speed and direction. This is important because currently-available air dispersion models use ambient or modeled wind speed and direction as input parameters. Thus, results will be useful in evaluating dispersion models for ground-level, horizontally-released, point sources and in developing effective pollutant remediation strategies for emissions.

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1. Introduction

Farms in the Delmarva Peninsula in the Mid-Atlantic region of the United States produce nearly 600 million broilers annually with over 3 billion dollars in wholesale value (Delmarva Poultry Industry Inc., 2016). The poultry industry is one of the most important industries supporting the local economy. In Delaware, 270 chickens were produced per person annually in 2010 (Pew Environment Group, 2011), and Sussex County in Delaware was ranked first nationally in poultry products (US Census of Agriculture, 2012). However, the rapid expansion and consolidation of concentrated poultry operations has raised concerns among local jurisdictions

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and environmental groups about pollutant emissions and the resulting negative effects on public welfare in the Delmarva area (Menefee, 2017; Vaughn, 2017).

Poultry houses in the US are ventilated with large sidewall fans. Poultry-house air pollutants include particulate matter (PM), ammonia, and volatile organic compounds (VOC) (Pescatore et al., 2005; Ritz et al., 2004; Cambra-López et al., 2010). PM is generally classified as total suspended particulate (TSP), PM with an aerodynamic equivalent diameter of less than 10 μm (PM_{10}), and PM with an aerodynamic equivalent diameter of less than 2.5 μm ($PM_{2.5}$) (US EPA, 2017). The main source of poultry house emissions is poultry litter, which is a mixture of manure, used bedding, waste food, and feathers (Carey et al., 2004). These air pollutants can have detrimental effects on air quality in the surrounding areas, but can also pose a risk to human health. $PM_{2.5}$ and PM_{10} are criteria air pollutants regulated under the Clean Air Act due to the potential for causing breathing and respiratory system problems (US EPA, 2017). Ammonia is also considered a respiratory irritant for humans at certain concentrations (ATSDR, 2011) and is a precursor to secondary inhalable particulate, $PM_{2.5}$ (Erisman and Schaap, 2004).

Previous studies examining poultry house air pollutants have focused on estimating PM and ammonia emission factors (Roumeliotis and Van Heyst, 2008). However, little research has been conducted concerning the PM and ammonia emission plume characteristics and concentrations downwind from the tunnel fans. Before strategizing control and remediation techniques, it is crucial to characterize these emission plumes and to document important interactions among the pollutants and environmental conditions which influence their dispersion. Therefore, we measured the PM and ammonia concentrations downwind from a commercial poultry facility, simultaneously at multiple horizontal and vertical locations, to gather essential information on the relationship between total suspended particulate (TSP), PM_{10}, $PM_{2.5}$, and ammonia emissions. An array-style sampling approach allowed for characterization of the effects of meteorological conditions on the pollutant concentrations and particle size distribution. Field observed PM and ammonia concentration data were used to estimate emission factors.

2. Materials and methods

2.1. Site and sampler array description

Ten experiments were conducted in May 2015 (late spring) at a farm in Delaware which consisted of two poultry houses (122 m length × 21 m width) with approximately 28,000 boilers per house. Each flock was raised on used litter for 60 days with a 10-day inactive time between flocks which is typical of a poultry farm in this region. During the campaign, the birds were approximately six to seven weeks old with no flock changes. The lighting program inside the house was 23 h of light and 1 h of dark. Each poultry house was ventilated by five 1.3-m tunnel fans located on both sides of the houses at one end of each house. The houses were also equipped with six tunnel fans on the opposite wall and directed in the opposite direction to the measured fans and with three end-wall fans, but these three fans were not used during any of the experiments. The fans were operated with seven different stages based on the housing temperature. The ventilation rate of each fan was calibrated *in-situ* by a fan assessment numeration system (FANS) at different static pressures. The ON/OFF status and operating static pressure of each fan were measured by magnetic current switch sensor and static pressure sensors, respectively, and recorded by ON/OFF status and analog data loggers. The ventilation rate was derived by coupling the fan runtime and static pressure.

Five daytime (D1, D2, D3, D4, and D5) and five nighttime experiments (N1, N2, N3, N4, and N5) were carried out. During each experiment, three 10-m sampling towers (T1, T2 and T3) with multiple sampling heights were deployed perpendicularly to the primary ventilation fans of poultry house one at 2, 23, and 47 m (Fig. 1). TSP sampler inlets and Radiello® samplers were mounted to four cross bars (1, 2, 3, and 4) attached to each tower at 2, 4.5, 7.25, and 10 m above ground level, respectively. Four sampler locations (S1, S2, S3, and S4) were positioned on both sides of the towers at 23 and 47 m from the poultry house and 2 m above ground level. A background sampler location was deployed approximately 70 m east of the tunnel fans and 2 m above ground level.

2.2. Meteorological measurements

Meteorological measurements were recorded every 16 s at each sampling point and at the background sampler for the duration of each experiment. Atmospheric pressure data were acquired using a 15 pisa board mount pressure sensor (TE Connectivity Corporation, Berwyn, PA), relative humidity using a HTM2500LF humidity sensor (TE Connectivity Corporation, Berwyn, PA), and wind speed and wind direction data using a 034 B wind sensor (Met One Instruments, Inc. Grats Pass, OR).

2.3. Air sampling

For each experiment, composite TSP and composite ammonia samples were collected from 6.5 to 12 h (SI Table 1). PM and NH_3 sampling time were different for each experiment (deploying period difference: 1.10 ± 1.39 h) due to physical limitations in deploying all samplers simultaneously. Samples were transported to the respective laboratories, preserved following standard protocols, and analyzed within two weeks after collection.

2.3.1. Ammonia sampling and analysis

Commercial passive diffusive samplers (Radiello®, Sigma-Aldrich Co. LLC, Darmstadt, Germany) were used to measure ammonia concentrations. The Radiello® sampler consisted of a microporous polyethylene cartridge impregnated with phosphoric acid (RAD168) which was inserted in a blue diffusive body made from microporous polyethylene (RAD 1201, 1.7 mm thick, avg. porosity 25 ± 5 μm, diffusive path length = 18 mm). During collection, the gaseous phase ammonia forms ammonium as it is absorbed by the cartridge. The diffusive body served as a shield to eliminate any interference from PM, allowing measurement of only gas-phase ammonia. After collection, cartridges were preserved in sealed individual Radiello® tubes. All the samples were packed and transported to the USDA-ARS in Beltsville, MD. Samples were processed using procedures defined by Radiello (2006). Briefly, the ammonium on the cartridge was desorbed and reacted with phenol and sodium hypochlorite in sodium hydroxide buffer and using sodium pentacyanonitrosylferrate as a catalyst to form indophenol. The blue product was quantified using a UV/Visible-1800 spectrophotometer (Shimadzu Corp., Kyoto, Japan) at $\lambda = 635$ nm.

2.3.2. Particulate matter collection and analysis

TSP samples were collected on Teflon filters using low-volume TSP sampler inlets designed and manufactured by Texas A&M/USDA-ARS (Wanjura et al., 2005). After collection, filters were preserved in individual petri dishes sealed by electric tape, packed, and delivered to the USDA-ARS Air Quality Lab in Lubbock, TX for analysis. Prior to use and after sample collection, filters were conditioned in an environmental chamber (21 ± 2 °C; 35 ± 2% RH) for 48 h prior to gravimetric analyses. TSP masses were obtained by difference using a Mettler MX-5 microbalance (Mettler-Toledo Inc., Columbus, OH) in the environmental chamber. The TSP