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Characterization of gaseous pollutant and particulate matter emission rates from a commercial broiler operation part I: Observed trends in emissions

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ABSTRACT

This paper characterizes the emission rates of size fractionated particulate matter, inorganic aerosols, acid gases, ammonia and methane measured over four flocks at a commercial broiler chicken facility. Mean emission rates of each pollutant, along with sampling notes, were reported in this paper, the first in a series of two. Sampling notes were needed because inherent gaps in data may bias the mean emission rates.

The mean emission rates of PM_{10} and $PM_{2.5}$ were 5.0 and 0.78 g day^{-1} [Animal Unit, AU]$^{-1}$, respectively, while inorganic aerosols mean emission rates ranged from 0.15 to 0.46 g day^{-1} AU^{-1} depending on the season. The average total acid gas emission rate was 0.43 g day^{-1} AU^{-1} with the greatest contribution from nitrous and nitric acids and little contribution from sulfuric acid (as SO_2).

Ammonia emissions were seasonally dependent, with a mean emission rate of 66.0 g day^{-1} AU^{-1} in the cooler seasons and 94.5 g day^{-1} AU^{-1} during the warmer seasons. Methane emissions were relatively consistent with a mean emission rate of 208 g day^{-1} AU^{-1}.

The diurnal pattern in each pollutant's emission rate was relatively consistent after normalizing the hourly emissions according to each daily mean emission rate. Over the duration of a production cycle, all the measured pollutants' emissions increased proportionally to the total live mass of birds in the house, with the exception of ammonia.

Interrelationships between pollutants provide evidence of mutually dependent release mechanisms, which suggests that it may be possible to fill data gaps with minimal data requirements. In the second paper (Roumeliotis, T.S., Dixon, B.J., Van Heyst, B.J. Characterization of gaseous pollutants and particulate matter emission rates from a commercial broiler operation part II: correlated emission rates. Atmospheric Environment, 2010.), regression correlations are developed to estimate daily mean emission rates for data gaps and, using the normalized hourly diurnal patterns from this paper, emission factors were generated for each pollutant.

1. Introduction

Commercial poultry facilities are responsible for emitting a variety of pollutants. Of these pollutants, ammonia (NH_3) and particulate matter less than or equal to ten and 2.5 microns in diameter (PM_{10} and $PM_{2.5}$, respectively) have been focused on due to their detrimental effects on human health and the environment and abundance inside the poultry houses (Lacey et al., 2003; Phillips et al., 1995; Roumeliotis and Van Heyst, 2008; Wheeler et al., 2006). In Canada, 87% of the NH_3 emissions are attributed to agriculture and 82% of these emissions have been estimated to originate from primary livestock production (Kurvits and Marta, 1998).

Ammonia is the most prevalent alkaline gas in the atmosphere and associates with acidic gases to neutralize the pH. This neutralization process results in the formation of liquid and solid inorganic aerosols, typically in the $PM_{2.5}$ size fraction. Sulfuric, nitric, and hydrochloric acid are the three main acidic species that interact with NH_3 to form ammonium sulfate, ammonium bisulfate, ammonium nitrate and ammonium chloride, respectively (Anderson et al., 2003; Baek et al., 2004). As poultry houses experience elevated levels of ammonia, it may be possible that any acid gases present in the barn atmosphere will be neutralized prior to being emitted from the facility and contribute to the overall $PM_{2.5}$ burden.

Another gaseous pollutant of concern is methane (CH_4) but it has not been well characterized for poultry operations since, unlike ruminants, poultry do not generate large quantities of CH_4 in their digestive tract. Methane, however, can be generated from the anaerobic decomposition of the organic matter in the litter.

The objective of this paper was to quantify the emissions of PM_{10}, $PM_{2.5}$, inorganic aerosols in the $PM_{2.5}$ size fractionation, acid gases, ammonia, and methane from a commercial broiler chicken

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facility using discrete and continuous measurement techniques. Emission trends need to be characterized, both diurnally and seasonally, to be able to interpret any data gaps due to instrument calibration and failures. Influential house management and/or environmental factors that affect one or more of the pollutants also need to be considered in any data interpolation method. This paper, the first in a series of two, focuses on characterizing the emissions of numerous pollutants from a broiler facility over four production flocks. The second paper develops correlations needed to address the missing data gaps and provides estimates of total emissions (Roumeliotis et al., 2010).

2. Materials and methods

The commercial broiler chicken facility used in the current study was a single storey (150.5 m by 18.3 m), mechanically cross-ventilated house located just outside of Guelph, Ontario, Canada. The house used a litter floor with new bedding, either wheat straw or wood shavings, placed at the beginning of each bird production cycle. Feed was auger-fed to the birds through rows of troughs and water was delivered via nipple drinkers.

The house temperature and relative humidity were controlled using radiant pipe heaters and a staged ventilation program. Heaters were used for roughly the first ten days to maintain a temperature that gradually decreased from 34 to 27 °C. After this time, fans were used to provide air exchanges in order to continually decrease the temperature from 26 to 19 °C over the remainder of the production cycle. The facility used six variable speed fans (0.56 m diameter), 12 dual speed on/off fans (0.65 m diameter), and 10 single speed on/off fans (1.3 m diameter) for a total of 28 fans.

Two lighting schedules of either 23 or 18 h of light each day were used at different stages in the production cycle to control the sleeping patterns of the chickens. The 23 hour day^{-1} cycle was used for the first five to six days and again after 22–24 days until completion.

The measurement campaign spanned four production flocks of broilers of approximately 45,000 broilers from February to September 2009. These four flocks of broilers were raised during representative seasons for the geographic region of winter, spring, summer, and summer/fall, respectively.

During the four observed cycles, birds were raised from an average weight of 47 g to 1810 g over a period of 31–34 days.

2.1. Instrumentation

Reactive gases (ammonia, hydrochloric acid, nitric acid, nitrous acid, and sulfuric acid (as sulfur dioxide)) and inorganic aerosol species (ammonium bound with chloride, nitrate, and sulfate) were collected from inside the broiler house using an annular denuder system (ADS; URG-3000C-ADS; URG Corporation, Chapel Hill, NC, USA). Samples were collected three times a week with each sampling period lasting approximately one hour. The ADS consisted of a 2.5 micron sharp cut-size cyclone followed by a series of nine, three-channel glass annular denuders used to adsorb the reactive gases by coating their walls with either 1% phosphorous acid or 1% sodium carbonate solutions. This was followed by a two-stage filter pack that collected the inorganic aerosols on a Teflon and nylon filter.

Contents on both the annular denuders and filters were extracted following Winberry et al. (1999). All extracts were analyzed using an ion chromatography system (Dionex IC-2000 ICS; Dionex Corporation, Sunnyvale, CA, USA). The resulting cationic and anionic species were converted to their respective gaseous and particulate concentrations based on the extraction volume and the standardized air sample volume.

Continuous PM_{10} and $PM_{2.5}$ concentrations were measured using two DustTrak® aerosol monitors (Model 8520; TSI Incorporated, Shoreview, MN, USA) installed with 10 and 2.5 micron sharp cut-size inlet conditioners. Dust samples collected from the broiler house were used to adjust the calibration density of the DustTrak aerosol monitors.

For the summer production cycle, ammonia was measured using a chemiluminescent ammonia analyzer (Model 17C, Thermo Electron Corporation, Franklin, MA, USA) while methane was measured continuously using a back-flush gas chromatography system coupled with a flame ionization detector (Model 55C, Thermo Electron Corporation, Franklin, MA, USA).

Volumetric exhaust rates from the three different fan sizes were quantified using an Alnor® balometer kit (EBT721; Alnor Products, Shoreview, MN, USA) consisting of a capture hood and a 16 point velocity matrix connected to micromanometers.

2.2. Sampling procedures

Air samples were drawn from the longitudinal midpoint of the barn through four horizontally integrated inlets, positioned inside the broiler house at a distance of 2.5 m from the exhaust fans and at a height of 1.8 m. This location produced representative pollutant concentrations in the exhaust air while avoiding a large change in velocity between the inlets and surrounding air (Heber and Bogan, 2006). The ADS and DustTrak monitors were located inside the facility while the Model 17C and 55C were situated in a climate-controlled trailer located on the fresh air intake side of the facility.

The house ventilation was managed by a 14 progressive stage, automated control system that records power used by the three fan sizes. The balometer was used to measure representative flow rates for the fans used in each of the 14 stages. The hourly averaged total house ventilation was, then, estimated using the individual exhaust rates with continuously monitored power usage by the facility's ventilation.

In addition, temperature, relative humidity and pressure were continuously measured both inside and outside the facility. Water consumption, average bird weight, and mortalities were recorded daily. Litter moisture, pH, ammonium-N, total ammoniacal nitrogen, and extractable chloride, were quantified every three to five days from composite litter samples and subsequent lab analysis.

2.3. Emission rate calculation

Hourly averaged pollutant emission rates (E, g day^{-1} AU^{-1}) were calculated on an animal unit (AU, equivalent to 500 kg live weight) basis using the number of birds and their average mass (M, kg), the hourly exhaust concentration (C, g m^{-3}), the outdoor concentration (C_o, g m^{-3}), and the hourly total house ventilation rate (Q, m^3 day^{-1}) as (Wheeler et al., 2006):

$$E = \frac{(C - C_o)Q}{M} \times \frac{500\ \text{kg}}{\text{AU}} \quad (1)$$

Since the outdoor air concentrations could not be measured simultaneously with the indoor air concentrations, a single daily averaged value for C_o was estimated for each pollutant using a set of outdoor air measurements. The mean concentration ($\overline{C}_o$, g m^{-3}) from the outdoor set of measurements was adjusted using a statistical method designed to contain a specified proportion of the population with a specified confidence based on the standard deviation of the outdoor concentration measurements (S, g m^{-3}) and the uncertainty of the sample size, n, represented by the t-distribution with 95% coverage, $t_{0.95,n-1}$, as (McBean and Rovers, 1998):

$$C_o = \overline{C}_o + (t_{0.95,n-1})S \quad (2)$$

If an exhaust concentration was quantified to be lower than C_o, the emission rate was set to zero.