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Factors and characteristics of ammonia, hydrogen sulfide, carbon dioxide, and particulate matter emissions from two manure-belt layer hen houses

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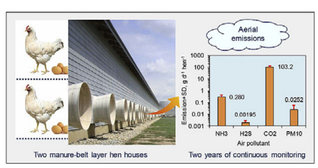
HIGHLIGHTS

- Pollutant emissions from two manure-belt layer houses were monitored for two years.
- Emission rates for NH_3, CO_2, H_2S and PM_{10} from the houses were obtained.
- Emissions of NH_3 and CO_2 were higher in winter than in summer.
- Emissions of all three gases were lower than reported high-rise layer houses.
- Emissions of PM_{10} exhibited a unique weekly variation pattern.

GRAPHICAL ABSTRACT



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ABSTRACT

Manure-belt layer hen houses are a relatively newer design and are replacing the old high-rise layer hen houses for egg production in USA. However, reliable aerial pollutant emission data from comprehensive and long-term on-farm monitoring at manure-belt houses are scarce. This paper reports the emission factors and characteristics of ammonia (NH_3), hydrogen sulfide (H_2S), carbon dioxide (CO_2), and particulate matter (PM_{10}) from two 250,000-bird capacity manure-belt layer hen houses (B-A and B-B) in northern Indiana, USA. The 2-year continuous field monitoring followed the Quality Assurance Project Plan of the National Air Emission Monitoring Study (NAEMS). Only days with more than 18 h (or 75%) of valid data were reported to avoid biased emission calculation. The results of 2-year average daily mean (ADM) gas emissions per hen from the two houses, excluding emissions from their manure shed, were 0.280 g for NH_3, 1.952 mg for H_2S, and 103.2 g for CO_2. They were 67% lower for NH_3, 77% higher for H_2S, and 10% higher for CO_2 compared with reported emissions from high-rise layer hen houses. Emissions of NH_3 and CO_2 exhibited evident seasonal variations. They were higher in winter than in summer and followed the NH_3 and CO_2 concentration seasonal patterns. Annual emission differences were observed for all the four pollutants. Reduced emissions of the three gases were shown during periods of layer hen molting and flock replacement. The 2-year ADM PM_{10} emission from B-B was 25.2 mg d^{-1} hen^{-1}. A unique weekly PM_{10} emission pattern was identified for both houses. It was characterized with much

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lower Sunday emissions compared with the other single-day emissions of the week and was related to the weekly schedule of in-house production operations, including maintenance and cleaning.

1. Introduction

Confined animal feeding operations (CAFO) are sources of aerial pollutant emissions. The pollutants from CAFOs that are of greatest concern to the U.S. Environmental Protection Agency (U.S. EPA) are ammonia (NH_3), hydrogen sulfide (H_2S), carbon dioxide (CO_2), and particulate matter (PM). Building design and manure handling are two of the factors affecting emissions from poultry houses (Xin et al., 2011). Manure-belt layer hen houses are a relatively newer design and are replacing the popular high-rise layer hen houses for egg production in the U.S., although they have a longer history and are widely adopted in Europe (e.g., Nicholson et al., 2004; Hayes et al., 2006), where other house structures, e.g., enriched cage systems (Alberdi et al., 2016), are also prevailing. In the poultry industry, manure-belt houses generally have better air quality than high-rise houses and have been reported with lower NH_3 emission rates than high-rise houses in the U.S. (Liang et al., 2005). This is because more frequent manure removal from manure-belt houses greatly reduces concentrations and emissions of pollutant gases at the houses (Xin et al., 2011; Ni et al., 2012).

Because of the seasonal and diurnal variations of aerial pollutant emissions from CAFOs, long-term (>6 months) and continuous (or high frequency) monitoring is needed to obtain reliable emission factors and in-depth knowledge about emissions at field conditions. In the National Air Emission Monitoring Study (NAEMS) in the U.S., pollutant emissions from 38 commercial livestock and poultry buildings were continuously monitored for two years between 2007 and 2010 using state-of-the-science methodologies and technologies (Heber et al., 2008b). Eight of the 38 buildings were large layer hen houses, of which six were high-rise houses at three commercial farms in California (Lin et al., 2012), North Carolina (Li et al., 2013; Wang-Li et al., 2013; Wang et al., 2016), and Indiana (Ni et al., 2017). In addition to the two high-rise houses, two manure-belt houses in Indiana were also monitored for the NAEMS.

The objective of this article was to present the emissions of NH_3, H_2S, CO_2, and PM_{10} from the two manure-belt layer hen houses, and the characteristics of emissions as affected by different factors during the monitoring from January 1, 2008 through December 31, 2009.

2. Materials and methods

As part of the NAEMS project, the monitoring at the Indiana site was conducted based on the Quality Insurance Project Plan (QAPP) (Heber et al., 2008a), which was reviewed and approved by the U.S. EPA (United States Environmental Protection Agency). In addition to the detailed design, operation, and quality control of monitoring at the 38 commercial livestock and poultry buildings, the QAPP also included 45 Standard Operating Procedures (SOP) for various methods, and sensors and analyzers.

2.1. Monitoring site

2.1.1. Layer hen houses

This study was conducted at a typical commercial egg production farm located in northern Indiana. The farm consisted of an egg-processing plant and multiple layer hen houses of different designs. Aerial pollutant emissions reported in this paper were measured at two of the manure-belt houses, denoted here as B-A and B-B, to be consistent with the previous publication (Ni et al., 2012). Both houses were built in 2004, oriented east-west, and measured 140.2 m long, 19.5 m wide, and 11.5 m high (Fig. 1). The houses were equipped with manure drying tunnels at the north and south side of the houses. There was also a manure shed (not shown in Fig. 1) at the east side of the houses to store manure from these two houses. However, assessment of pollutant emissions from the manure drying tunnels and the manure shed is not within the scope of this paper.

2.1.2. Layer hens, manure, and manure removal

Layer hens (W36) were raised in Facco type cages (Facco & C. Officine, Campo San Martino, Italy) in seven rows and 10 tiers in each house and were molted according to industry standards. Molting in B-A started in the week of January 10, 2009 and finished in the week of February 28, 2009. Molting in B-B occurred from the week of December 5, 2009 to the week of January 16, 2010. Layer hen inventory, average hen weight, and egg production were recorded by the egg producer.

Layer hen manure dropped from the cages to 1.21-m wide plastic belts beneath each tier of cages. The belts were moved one third of the house length from west to east for approximately 4 h in the morning each day except on Sundays. Thus, it took a maximum of 4 days for manure at the west end of the house to be removed out of the east end of the house and entered into the top of the 16-tier manure drying tunnels located in front of 13 (B-A) or 14 (B-B) exhaust fans on each side wall of the houses (Fig. 1). The dried manure from the bottom of the tunnels was then transferred via conveyers to a manure shed located to east of the two houses.

2.1.3. House ventilation

Outdoor fresh air entered the houses from the attic through seven equally-distanced and baffled ceiling inlets that were controlled based on indoor air temperature (T). There were eighty-eight 1.32-m diameter exhaust fans on the sidewalls and east end wall of each house (Fig. 1). Among them seven (Fans 1, 10, 21, 25, 28, 30, and 33) on each sidewall were variable-speed fans that operated continuously. The remaining 74 fans in each house were single-speed fans that were grouped into 12 ventilation stages. Two building environmental control systems (Fancom, Panningen, The Netherlands) controlled all the variable- and single-speed fans. Other eight fans were located at the top of the outer walls of the drying tunnels at each house, assisting air exhausting from the tunnels. The distributions of the fans in B-A and B-B were almost identical except for Fans 20 to 33.

2.2. Monitoring system

2.2.1. Instrument shelter and computer system

An on-farm instrument shelter (OFIS), or mobile laboratory, was set up near the southeast corner of B-B. A heating, ventilation, and air conditioning system maintained operational temperatures for the equipment inside the OFIS, in which an on-site computer system (OSCS) and all gas analyzers and other instruments were installed.