Atmospheric Environment 154 (2017) 260–273

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Emission factors and characteristics of ammonia, hydrogen sulfide, carbon dioxide, and particulate matter at two high-rise layer hen houses

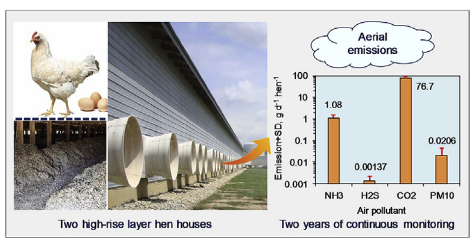
Ji-Qin Ni [a,*], Shule Liu [a], Claude A. Diehl [a], Teng-Teeh Lim [b,1], Bill W. Bogan [a], Lide Chen [c,1], Lilong Chai [d,1], Kaiying Wang [e,1], Albert J. Heber [a]

[a] Agricultural and Biological Engineering, Purdue University, USA
[b] Food Systems and Bioengineering, University of Missouri, USA
[c] Biological and Agricultural Engineering, University of Idaho, USA
[d] Agricultural and Biosystems Engineering, Iowa State University, USA
[e] School of Biosystems Engineering and Food Science, Zhejiang University, China

HIGHLIGHTS

- Pollutant emissions from two commercial layer houses were monitored for two years.
- Emission factors 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 summer.
- Significant emission variations were observed between the two houses.
- Emission variations for the same houses were also observed between the two years.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 October 2016
Received in revised form
23 January 2017
Accepted 27 January 2017
Available online 30 January 2017

Keywords:
Agricultural air quality
Animal agriculture
Air pollution
Emission baseline
Pollutant emission
Poultry house

ABSTRACT

Air pollutants emitted from confined animal buildings can cause environmental pollution and ecological damage. Long-term (>6 months) and continuous (or high frequency) monitoring that can reveal seasonal and diurnal variations is needed to obtain emission factors and characteristics about these pollutants. A two-year continuous monitoring of ammonia (NH_3), hydrogen sulfide (H_2S), carbon dioxide (CO_2) and particulate matter (PM_{10}) emissions from two 218,000-hen high-rise layer houses (H-A and H-B) in Indiana, USA was conducted from June 2007 to May 2009. Gaseous pollutant concentrations were measured with two gas analyzers and PM_{10} concentrations were measured with three Tapered Element Oscillating Microbalances. The operation and performance of ventilation fans were continuously monitored with multiple methods. Only the emission rates calculated with valid data days (days with more than 18 h, or 75%, of valid data) are reported in this paper. The two-house and two-year mean ± standard deviation emissions per day per hen for NH_3, H_2S, CO_2, and PM_{10} were 1.08 ± 0.42 g, 1.37 ± 0.83 mg, 76.7 ± 14.6 g, and 20.6 ± 22.5 mg, respectively. Seasonal emission variations were demonstrated for NH_3 and CO_2, but not evident for H_2S and PM_{10}. Ammonia and CO_2 emissions were higher in winter than in summer. Significant daily mean emission variations were observed for all four pollutants between the two houses ($P < 0.05$), and between the two years from the same house ($P < 0.01$) except for CO_2 at one house. Carbon dioxide originated from manure decomposition was >9% of that from bird respiration.

* Corresponding author. Department of Agricultural and Biological Engineering, Purdue University, 225 S University St., West Lafayette, IN 47907, USA.
E-mail address: jiqin@purdue.edu (J.-Q. Ni).
[1] Current address.

http://dx.doi.org/10.1016/j.atmosenv.2017.01.050

Emissions of CO_2 during molting were about 80% of those during normal egg production days. Emissions of H_2S were not a major concern due to their very low quantities. Emissions of PM_{10} were more variable than other pollutants. However, not all of the emission statistics are explainable.

1. Introduction

Confined poultry houses are sources of aerial pollutants, of which ammonia (NH_3), hydrogen sulfide (H_2S), carbon dioxide (CO_2), and particulate matter (PM) are most concerned for indoor air quality and pollutant emissions from the houses. Ammonia in poultry facilities is released from manure. It has been known since the early 1950s that NH_3 is a major gaseous pollutant in poultry facilities. It is noxious and odorous, and can affect poultry health and welfare (Faddoul and Ringrose, 1950; Kristensen and Wathes, 2000). Ammonia is also of great environmental concern when excessive quantities are emitted to the outdoor atmospheric environment because it can contribute to the acidification of soil and nitrogen deposition in ecosystems (NRC, 2003). Moreover, NH_3 is a precursor to aerial nitrous oxide (N_2O) and secondary particles (Hallquist et al., 2009). Hydrogen sulfide is odorous and toxic. It is also the most dangerous gas from liquid animal manure. It has been responsible for many animal and human deaths in animal facilities (Oesterhelweg and Puschel, 2008; Riedel, 2011). Carbon dioxide in animal agriculture originates from both animal respiration and manure breakdown. It can affect animal health and welfare at high concentrations in confined buildings. It is also frequently used to estimate poultry house ventilation rates (e.g., Koerkamp et al., 1998; Liang et al., 2005). High concentrations of PM can threaten the environment as well as the health and welfare of humans and animals (Cambra-Lopez et al., 2010). The health effects of PM are well documented and there is no evidence of a safe level of exposure or a threshold below which no adverse health effects occur (WHO, 2013).

Emission rates of aerial pollutants from animal buildings are needed to assess the impacts of aerial pollutants on environments and ecosystems, assist environmental protection policy-making and law enforcement, and potentially develop and apply mitigation technologies. In 2000, the U.S. EPA began applying federal air quality standards to animal feeding operations (AFOs). However, it was found that the aerial emission estimates available for AFOs were, in many cases, based on data that were outdated and inappropriate for agriculture at the time (Schutz et al., 2005). Though several studies on aerial emissions had been conducted on layer hen facilities, some of them were either survey-type investigations, or of short duration or intermittent measurements, or conducted a couple of decades ago (e.g., Wathes et al., 1997; Takai et al., 1998). Moreover, long-term (>6 months) and continuous (or high frequency) monitoring at field conditions was needed to reveal seasonal and diurnal variations and obtain in-depth knowledge about aerial pollutant emissions from animal agriculture.

The National Air Emissions Monitoring Study (NAEMS) was launched in the U.S. in 2006 to quantify aerial pollutant emissions from animal production facilities, provide reliable data for developing emission models, and promote a national consensus on methods and procedures for measuring emissions from AFOs (Heber et al., 2008b). As part of the NAEMS, aerial emissions from eight large layer hen houses, of which six were high-rise houses, were continuously monitored at three commercial farms in California, North Carolina, and Indiana for two years between 2007 and 2009 using state-of-the-science methodologies and technologies. The monitoring has generated one of the largest air quality datasets for the layer hen industry to date.

Among the three NAEMS layer hen monitoring sites, the sites in California (Lin et al., 2012) and North Carolina (Wang-Li et al., 2013a) each consisted of monitoring of two commercial high-rise houses. The site in Indiana consisted of two high-rise and two manure-belt houses (Ni et al., 2012). The objectives of this article are to (1) obtain emission factors of NH_3, H_2S, CO_2, and PM_{10} at the two high-rise layer hen houses in Indiana from the 2-year monitoring study, (2) compare emissions from similar sources reported in the literature, and (3) gain insight into the characteristics of emissions.

2. Materials and methods

2.1. Layer hen houses

The houses in this study were at a typical layer hen farm in Midwest USA. It was located in an agricultural area of Indiana, with no other identifiable emission sources (livestock or poultry farms or farms that periodically received manure) within 1.6 km of the site. Two of the high-rise layer hen houses (denoted as H-A and H-B), oriented east-west and constructed in 1997, were monitored from June 1, 2007 to May 31, 2009 (Fig. 1 and Table 1). Each house had a capacity of 250,000 hens and was 198.0 m long and 30.5 m wide. The two houses were spaced 17.0 m apart. Each house had a 5.0 m high sidewall and a 2.4 m high first-floor manure pit.

Layer hens were confined in ten rows of five-tier A-frame cages on the second or upper floor, and were molted according to industry standards. The cage lights were shut off for 8 h each night. Eggs were collected by conveyors into an on-farm egg processing plant. Egg production and water consumption of each house were recorded automatically each day. The producer weighed 100 hens from the same identified cages in each house once weekly to estimate the overall average hen weight in the house. Feed consumption was recorded each week.

Manure dropped off slanted boards behind the cages directly into the first floor manure pit, where it was stored until being loaded out and applied as fertilizer in cropland. Three manure removal events occurred during the study: from H-A in 2007 and 2008, and H-B in 2007. The net weights of the load-out manure were obtained by weighing each truck-load of manure with a truck weighing scale. Manure samples were taken from the load-outs and analyzed in a commercial laboratory. The analyses included percentage of total solids.

2.2. House ventilation

Ventilation air entered the cage level from the attic through three temperature-adjusted V-shaped and baffled ceiling air inlets in three temperature (T) control zones. Twelve T sensors per house were distributed equally at cage level and used to control indoor T. There were 110 belt-driven ventilation fans of 1.22 m diameter (Model AT481Z1CP, Aerotech Inc., Mason, MI, USA) distributed along the west and east sidewalls in each house in the first floor and operated in 13 ventilation stages. Ten of the 110 fans were variable-speed and constituted the first stage of ventilation. The fan speed