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Ammonia Emissions from U.S. Poultry Houses: Part I—Measurement System and Techniques

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Abstract

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Keywords

Animal feeding operations (AFOs), Air quality, Ammonia emissions, Poultry

Disciplines

Bioresource and Agricultural Engineering

Comments

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AMMONIA EMISSIONS FROM U.S. POULTRY HOUSES: PART I – MEASUREMENT SYSTEM AND TECHNIQUES

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ABSTRACT

A multi-state, multi-disciplinary research project is currently underway to quantify aerial ammonia (NH₃) emissions from selected US poultry houses with different housing and management schemes. A series of publications will result from this study. This paper highlights the system and techniques used by the participating institutions to continuously measure NH₃ and carbon dioxide concentrations and determine building ventilation rate. Specifically, a portable monitoring unit (PMU) has been developed and refined for field measurement and acquisition of NH₃ level, CO₂ level and building static pressure. Ammonia level is measured with electro-chemical sensors that undergo cyclic purging to avoid sensor saturation. Building ventilation rate is directly measured by calibrating the airflow rates of fans in-situ with a Fan Assessment Numeration System (FANS) device and recording of fans runtime, or indirectly calculated using the CO₂ balance method based on the latest metabolic rate information for the modern birds (W-36 laying hens). Comparative tests were conducted between the PMU and a chemiluminescence NH₃ analyzer in a field emission laboratory (FEL), and there were no significant differences between the two measurement methods (P=0.33).

KEYWORDS. Animal feeding operations (AFOs), Air quality, Ammonia emissions, Poultry.

INTRODUCTION

Ammonia (NH₃) is the primary aerial pollutant in poultry production houses, resulting from biodegradation of bird feces. Ammonia is specifically designated as a particulate precursor, and as such has focused air quality regulatory attention on the livestock and poultry industry. Collection of sound baseline data on gaseous, odor, and particulate emissions from concentrated animal feeding operations (CAFOs) and investigation of emission mitigation strategies under the U.S. animal production conditions are therefore pressing air quality issues facing the U.S. animal industry, academic community, and regulatory agencies (National Academy of Science, 2002). A concern for the US poultry industry as well as for the regulatory agencies is to ensure that reasonable estimates of emission source contributions to US air pollution are used. Currently, data are lacking for such estimates.

The term CAFO emission can refer to concentration or emission rate of the substance under consideration. Emission rate (ER) or emission factor (EF) describes the amount of pollutants emitted from a CAFO to the atmosphere over certain time period; whereas concentration refers to the level of the substance in the air either at or downwind from the source. The former deals with emission inventory and the latter provides the basis for assessing compliance of a CAFO with certain air quality standards in the vicinity of a CAFO, such as the one being proposed in the Iowa Air Quality Report (Iowa State University and the University of Iowa, 2002). Emission rate is technically the product of source concentration of the substance and the air exchange rate through the source. Past experiences have shown that it is a formidable task to reliably quantify either of the two variables in CAFOs on a continuous and prolonged basis. The challenge lies in

the harsh nature of the sample air that is beyond the operational limits of most analytical instruments; prohibitive costs of the high precision instruments; the large number of facilities and geographical locations that must be monitored to ensure reasonable representation of the wide-range production practices; limited mobility of the expensive instruments (e.g., field emission lab) once installed on site; the large number of fans involved and the inherent variations among them (belt tightness, degree of shutter opening, dust on blades, etc.) for certain mechanically ventilated facilities (e.g., laying hen houses); and the high difficulty in determining ventilation rate for naturally ventilated facilities. Nevertheless, researchers continue to explore measurement instruments and techniques that are relatively affordable and acceptable in performance to meet the increasing needs to quantify emission rates and evaluate mitigation strategies.

The objective of this paper is to describe the measurement instrumentation system used in a current multi-state project that aims to quantify ammonia emission rates from selected, representative U.S. broiler and laying hen houses with various housing and manure/litter management schemes and geographical locations. Two companion papers describe progress results on emission rates for broiler houses in Kentucky and Pennsylvania (Wheeler et al., 2003) and laying hen houses in Iowa (Liang et al., 2003).

METHODOLOGY AND SAMPLE RESULTS

The guiding principles in selecting and developing the measurement system for this project was: a) the monitoring unit should have a reasonable resolution or repeatability in measuring NH₃ levels in most U.S. poultry houses, so that a maximum number of units could be built and operated with the available funds; b) the unit should be truly portable in that it can be readily moved among the monitored sites, thereby maximizing the number of houses monitored in the project; and c) the unit conforms to biosecurity protocols in that it has a well-sealed housing (not opened on site) and its wetted parts (plumbing) can be disinfected or purged off site. It was based on these guiding principles that the portable monitoring units (PMUs) were developed. Monitoring of the houses is performed at 2-3 week intervals, and each monitoring episode lasts about 2.5 days. Data on NH₃ level and other environmental variables (temperature, RH, CO₂, building static pressure) are collected at 30- or 60-s intervals, and later processed into 20- or 30-min data. The monitoring will last one full year to cover the seasonal effects on emissions. It is worthy noting that a parallel multi-state project involving six states (MN, IN, IA, IL, NC, and TX) uses field emission labs (FELs) to intensively quantify emissions of gases, dust and odors from a fewer number of swine and poultry houses. Thus, the two projects are complementary in scope and methodology. A side-by-side comparison of the PMU and FEL systems for measuring NH₃ levels at a commercial laying hen house has been conducted, as described below.

The Dual-Gas Portable Monitoring Unit (PMU)

The PMUs were built with commercially available components (~\$3,500 in material cost). Xin et al. (2002) described the development and operation of the first-generation PMU. It uses two electro-chemical (EC) NH₃ loggers (0-200±1 ppm, model PAC IIIh; Dräger Safety, Inc., Pittsburgh, PA¹⁰) and one infrared CO₂ transmitter (0-5,000 or 0-7,000 ± 20 ppm; Model GMT222, Vaisala Inc., Woburn, MA). The redundant NH₃ logger is used to minimize missing data due to sensor failure. One unique feature of the PMU is the purging of the EC-NH₃ sensors prior to sampling the target air. This purging is designed to eliminate errors caused by sensor saturation from continuous exposure to NH₃-laden air. Xin et al. (2002) presented data relative to the saturation behavior of the EC sensors and the responses of the sensors to cyclic purging and sampling. It was observed in both lab and field trials that the duration of purging depends on the NH₃ concentration in the sample air and the sensor life. For the applications of high-rise or manure belt laying hen houses where NH₃ level varies from less than 10 ppm to greater than 120 ppm, 24-min purging and 6-min sampling cycles (thus, 30-min concentration data) was found to be adequate. For broiler houses, 14-min/6-min cycles (20-min data) have been used. Through calibration with NH₃ + N₂ balance gas (18, 50 and 154 ppm), it was found that the maximum

readings during sampling cycle represent the actual NH_3 concentrations, and have been used in the calculations.

Figure 1 contains a photograph and a schematic of the second-generation PMU. The main difference between the first and second generation PMU is that the second-generation PMU uses positive pressure (PP) air sampling system (i.e., supply pump placed in the upstream of the NH_3 sensors) whereas the first generation PMU used negative pressure (NP) sampling system (pump placed downstream). The initial choice of NP sampling was to eliminate potential absorption of gas by the air pump. However, it seemed that undetectable leakage in the NP plumbing or change in sensor responsiveness over time made the readings with NP sampling less reliable or inconsistent between the paired sensors from time to time, when compared with hand-held measurements. Therefore, PP sampling system was investigated. The results showed that readings of the sensors with PP sampling were much more consistent between themselves and when compared with the hand-held monitor readings. The effect of gas absorption by the sampling pump on NH_3 readings during the sampling cycles was also found negligible, presumably due to the large volume of air (~ 11 l/min) moving through the pump and only an aliquant amount (0.5 l/min) passes through the NH_3 sensors. However, the absorption seems to affect (elevate) NH_3 readings during the purging cycles.

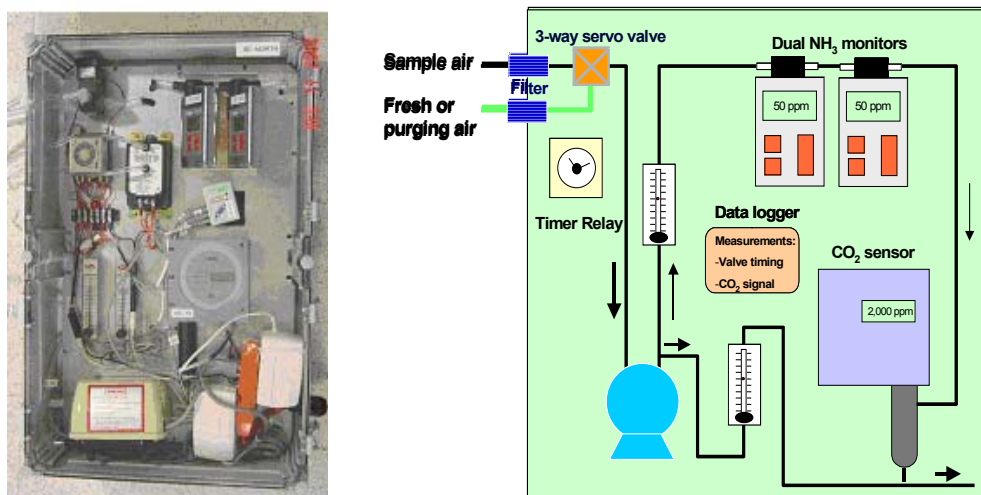


Figure 1.-The dual-gas (NH_3 & CO_2) portable measurement unit (PMU): *Second generation*. Differing from the first generation PMU, it uses positive-pressure (PP) air delivery

An example output of the NH_3 and CO_2 readings of the PS PMU during purging (low pulse in the valve state) and sampling (high pulse in the valve state) cycles in monitoring a commercial high-rise laying hen house in wintertime is shown in Figure 2. The gradual elevation in NH_3 values during purging cycles was presumably a result of slow release of gas absorbed into the sampling pump. Also differing from the first-generation PMU, the second-generation PMU uses the much lighter polycarbonate enclosure with a transparent door (Hoffman Electrical Enclosure Cat. No. Q604018PCIQRCC, Crescent Electric Supply Company, Des Moines, IA) instead of the metal enclosure.

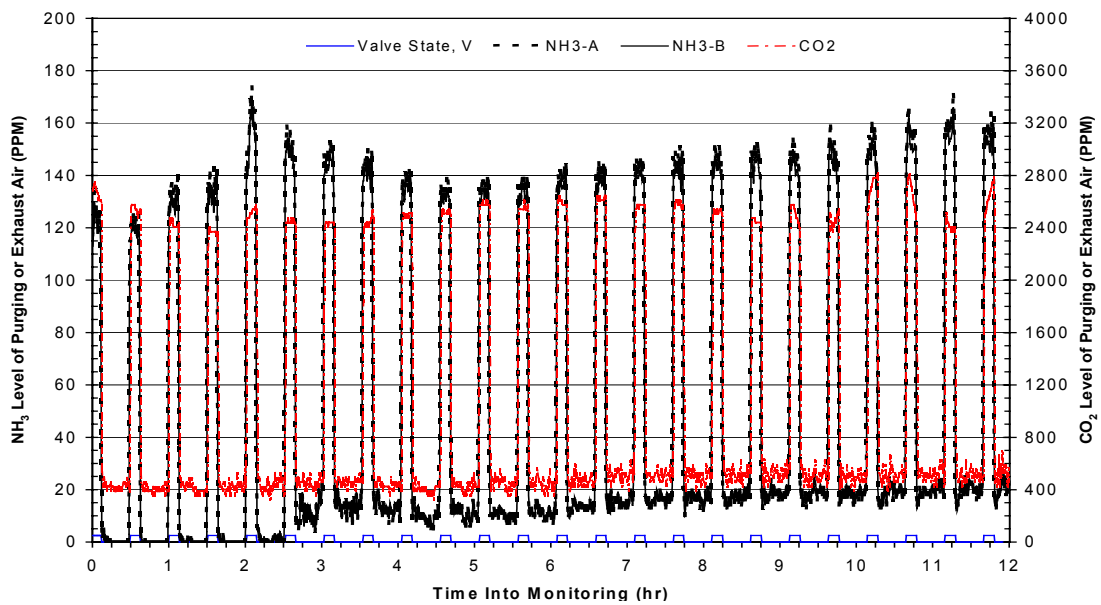


Figure 2. An example output of 30-s NH₃ and CO₂ monitors of the PMU for the incoming (purging) and exhaust air in a high-rise laying house (with manure storage in the lower level) during wintertime.

The PP PMU was evaluated against a chemiluminescence NH₃ analyzer in a FEL that was installed next to a commercial laying hen house. The NH₃ levels monitored ranged from 6 to 45 ppm. The FEL recorded NH₃ levels of the exhaust air every minute whereas the PMU used 12-min purging and 8-min sampling cycles and registered data every 30 s. Averages of the NH₃ readings by the FEL during the PMU sampling cycles were calculated. These average values were compared with a) the maximum value of the PMU readings during the sampling cycles (PMU_{max}), b) the difference between the maximum value of sampling cycle and the minimum value of purging cycle (PMU_{max-min}), or c) the difference between maximum value of sampling cycle and mean value of last 2-min of the purging cycle (PMU_{max-2min}). Selection of the different values was based on the inherent characteristic (potential sensor saturation) of the electrochemical sensors to NH₃-laden air. Paired t-tests were conducted between the FEL and the PMU values; and the results are presented in Table 1. PMU_{max} values were the only one of the three scenarios that showed no significant difference from the FEL values (P=0.33).

Table 1. Comparison of ammonia concentration measured by PMU vs. chemiluminescence analyzer used in a field emission lab (FEL) at a laying hen house site (n = 1068)

Term	Mean of FEL-term	SD	t value	P-value
PMU _{max}	-0.1	3.2	- 0.971	0.3317
PMU _{max-min}	0.7	3.4	7.085	<0.0001
PMU _{max-2min}	2.1	3.5	19.84	<0.0001

Before and after each field monitoring, the NH₃ loggers are checked and calibrated as needed. The loggers are programmed to collect data every 30 or 60 s. At this interval, the PAC IIIh loggers can store up to 67 or 134 hr of data. At the end of 2.5-d monitoring episodes, the PMUs are handled in one of the two ways. Where the PMUs are shared among different monitored sites, they are brought back to the lab on campus and purged with fresh air before they are opened and data downloaded. The exposed surface areas of PMUs are cleaned/wiped with disinfectant before they are taken to the next site. Where PMUs are designated to specific sites, only the PAC IIIh monitors and the 4-channel data logger containing the CO₂ output, the timer output (solenoid switch state of sampling or purging), interior temperature of the enclosure, and static pressure output (one per house) are brought back for data retrieval and calibration check. During post-monitoring check with calibration gases (close to the house NH₃ levels), if readings of both NH₃ loggers of the PMU agree within 95% of the target (calibration gas) values, averages of the two are used in the data analysis. Otherwise only data from the unit that agrees with the target values will be used. The CO₂ transmitters have been found to be stable and are checked

every 2-4 weeks and calibrated every six months using the commercially available calibrator (Model GMK220, Vaisala Inc., Woburn, MA).

Determination of Building Ventilation Rate and Emission Rate

Building ventilation rate (BVR) is determined by one of the two ways. One is direct measurement by measuring the airflow rates of selected or all ventilation fans with an improved in-situ Fan Assessment Numeration System (FANS) device (Gates et al., 2002; Wheeler et al., 2002) and monitoring the runtime of the fans. Fan motor activation is measured using a commercially available motor logger (Onset Computer Corp, MA). Numerous different configurations of logger installation were tested to get reliable fan motor activation data. The basic unit did not function reliably with the conventional capacitor start-capacitor run motors used to drive the propeller fans in all (broiler) sites (both 120 and 240 VAC). The most reliable method being used involves fastening the motor logger to a custom-fabricated extension cord with a single conductor placed near one part of the unit, and the other conductor and ground wire placed at the end of the logger (Figure 3).

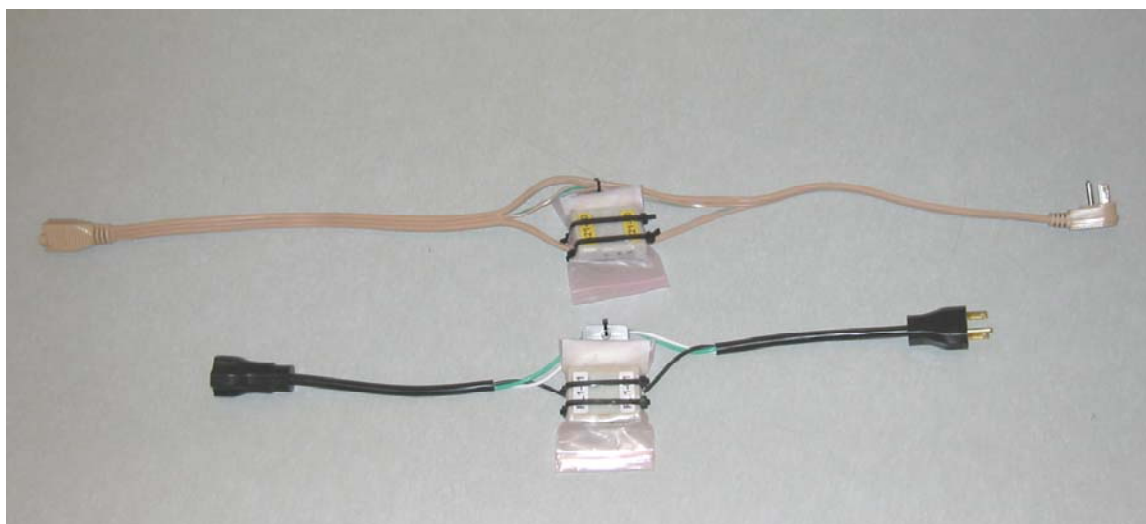
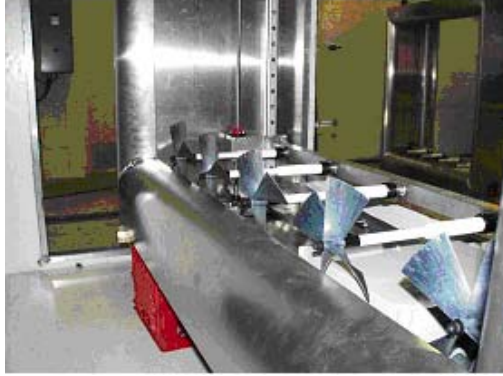


Figure 3. Custom-fabricated extension cord used to attach motor logger for monitoring fan operation.

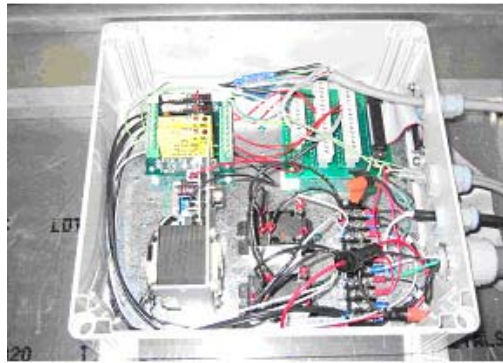
Figure 4 shows photographic views of the FANS. Ten FANS units have been constructed for use by the two multi-state projects. The FANS units were individually calibrated at the University of Illinois BESS fan testing facility (<http://www.age.uiuc.edu/bee/research/research.htm>). Figure 5 is a graph of measured vs. "true" airflow curves for all 10 units. Considerable variations in airflow rates among individual, seemingly identical fans can exist. An example is shown in figure 6 that involves eight 1.2-m (48 inch) fans installed in a tunnel-ventilated broiler house, as measured with the FANS. These large discrepancies among the individual fans further demonstrate the need to verify or calibrate the ventilation fans for their actual air delivery capacities, as opposed to relying on the manufacturer's rating.



(a)



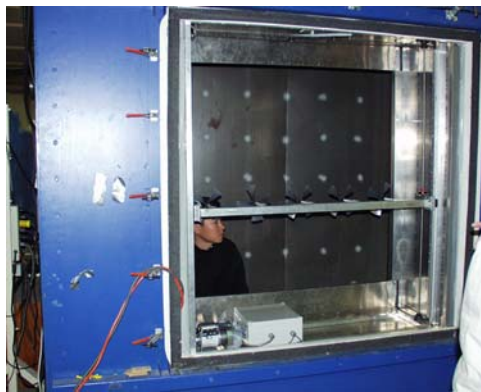
(b)



(c)



(d)



(e)



(f)

Fig. 4-FANS unit photographs: (a) recently built units; (b) anemometer rack; (c) electronics for controlling drive-train and acquiring anemometer signals; (d) FANS unit in trailer for transport to site; (e) calibration in the University of Illinois BESS Lab; (f) calibration at BESS with fan in place (Source: Gates et al., 2002).

The other method of determining BVR is through CO₂ balance as governed by indirect calorimetry relation. The metabolic rates and respiratory quotients of modern W-36 breed laying hens (type of hens used in this project and most typical in the United States) during light and dark periods of the day have recently been quantified (Chepete, 2002). With two 0.9-m (36-inch) fans running at an average static pressure of 25 Pa (0.10" W.C.), producing a nominal airflow of 8.0 – 9.9 m³/s (17,000-21,000 cfm, Online Agricultural Fans Performance and Efficiency, BESS Lab, <http://www.bess.uiuc.edu>), the calculated daily mean CO₂ balance-based BVR was 8.7 m³/s (18,368 cfm). Hence the preliminary results indicate that the CO₂ balance method produces reasonable estimation of BVR under the minimum ventilation condition. More extensive evaluation of the CO₂ balance BVR estimation vs. mechanical measurement is ongoing. Based on the indirect determination of BVR, Figure 7 shows an example diurnal profile of NH₃ emission rates for a high-rise layer house and a manure belt layer house during wintertime. The results of these diurnal variations confirm the necessity for continuous, extended measurement vs. brief, snapshot measurements to ensure a realistic representation of overall emission rate.

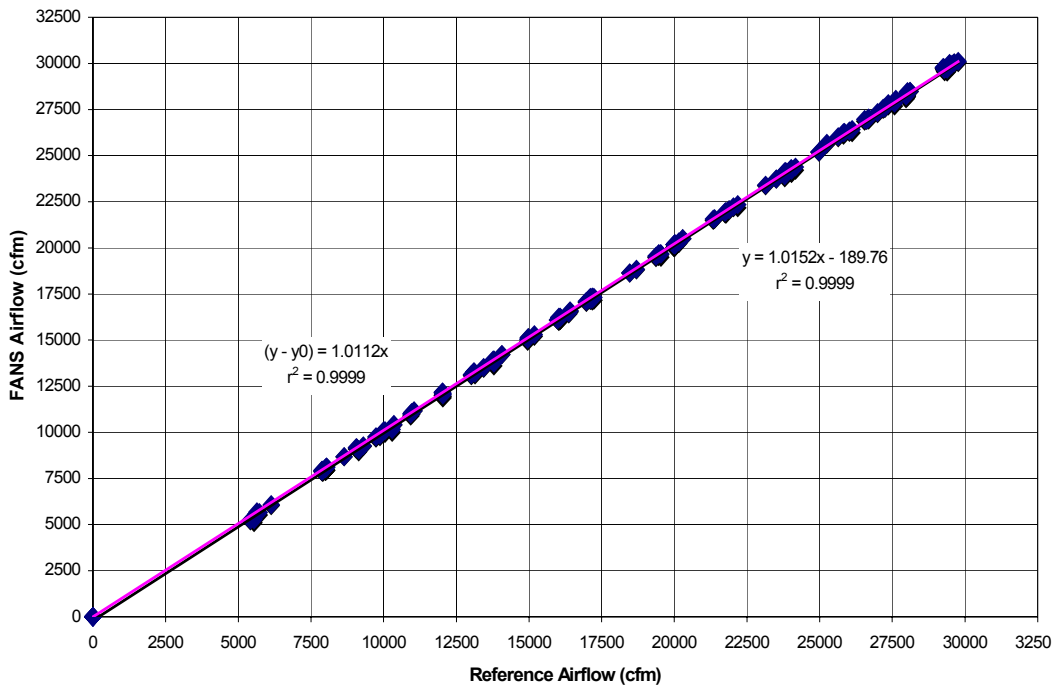


Figure 5. Composite graph illustrating the uniformity of measurement between 10 different FANS units. Reference flow obtained from standard flow nozzle equations for the nozzles in the BESS Lab (Univ. of IL) from manometer readings of pressure drop (Source: Gates et al., 2002). 1 cfm = 1.7 m³/hr

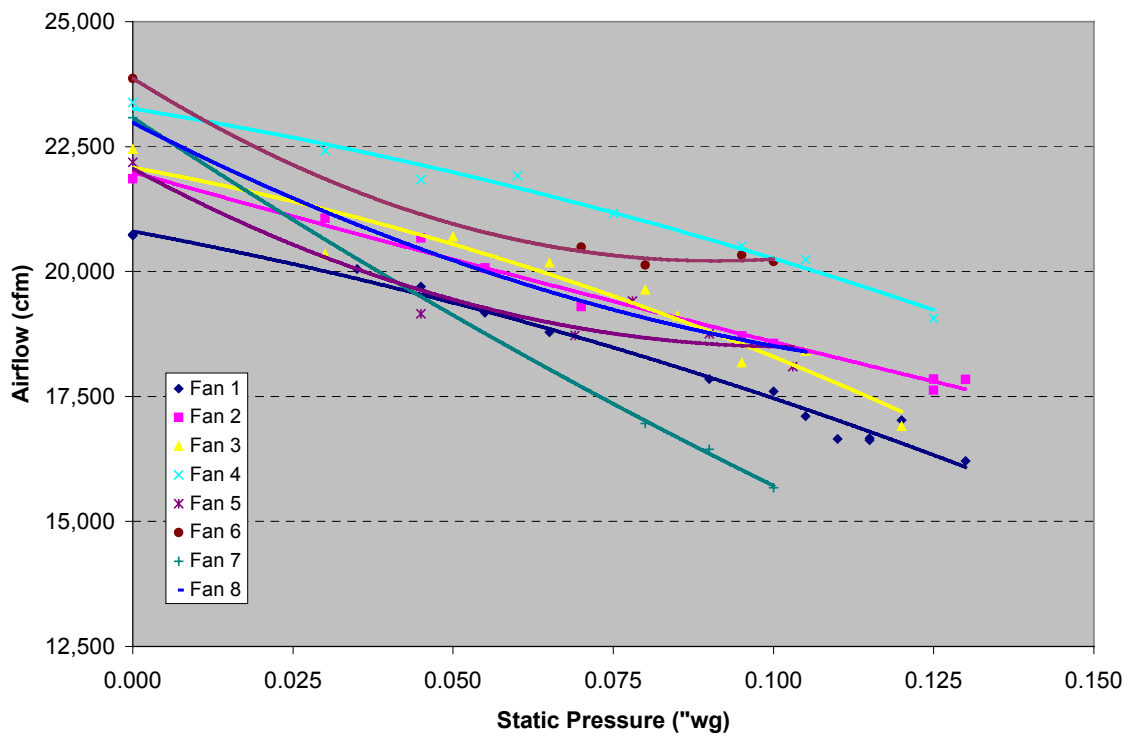


Figure 6. -Illustration of considerable variations in airflow rates among eight 1.2-m (48 inch) diameter ventilation fans installed in a tunnel-ventilated broiler house, as measured with the FANS (Source: Casey et al., 2002). 1 cfm = 1.7 m³/hr.

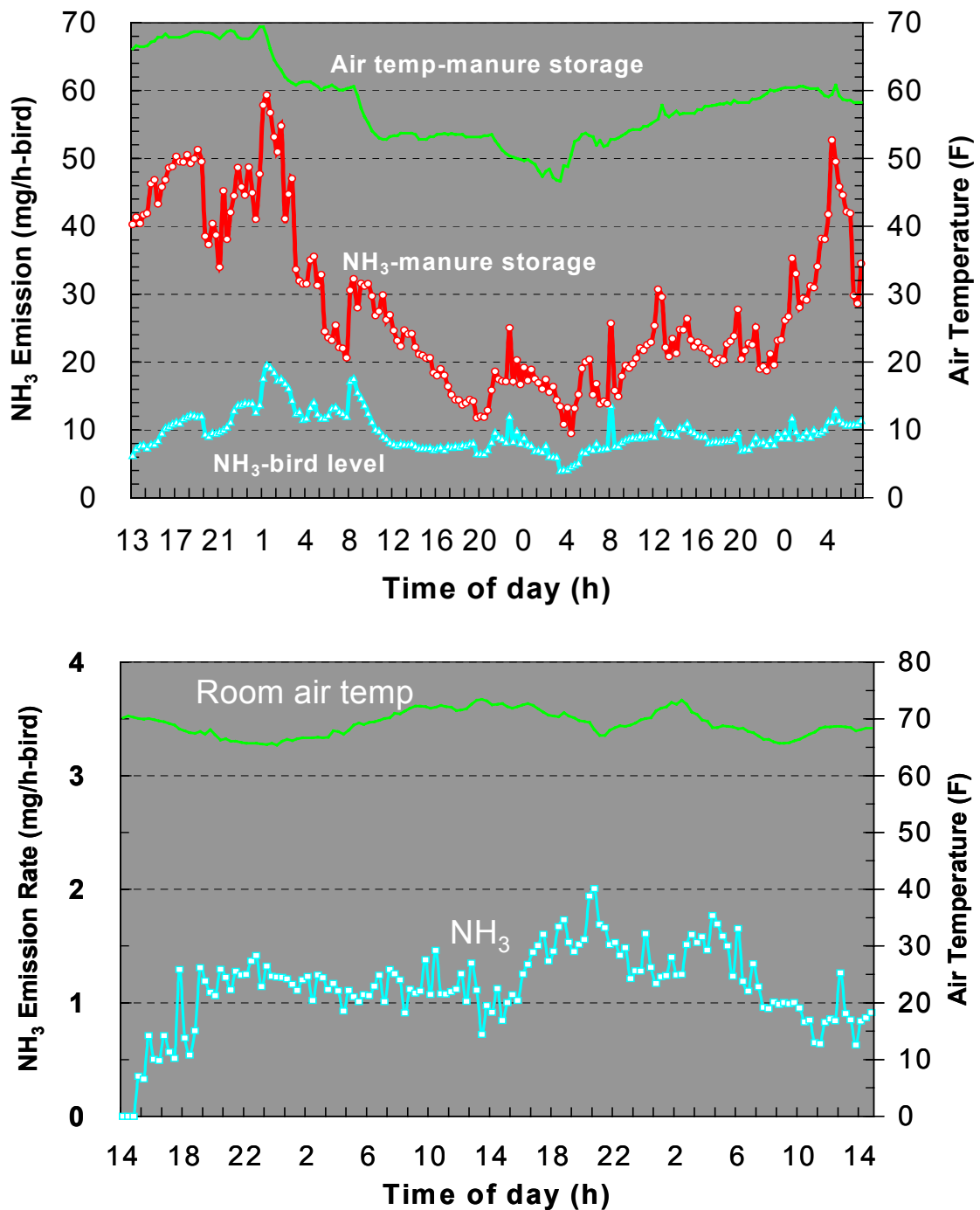


Figure 7. Example dynamic profiles of NH₃ emission rate for a high-rise (top) and manure belt (bottom) laying hen house during wintertime. °C = (°F-32) × 5/9

SUMMARY

A relatively low-cost, portable measurement instrumentation system was developed and is being used for continuous measurement of ammonia (NH₃) and carbon dioxide (CO₂) levels, in-situ calibration of fan airflow capacity, and fan runtime in commercial poultry houses. These measurements lead to quantification of NH₃ emission rates from the animal houses. Specifically, the NH₃ and CO₂ levels are measured and recorded with one or multiple portable monitoring unit(s) (PMUs) that operate(s) in purging and sampling cycles. The actual airflow rates of ventilation fans are calibrated with an improved Fan Assessment Numeration System (FANS) device. Runtime of the ventilation fans (in tunnel-ventilated broiler houses) is monitored using

commercially available magnetic motor loggers attached to custom-made extension cords that are connected to the power supply of the exhaust fans. The NH₃ levels measured with the positive pressure system PMU (maximum values of the sampling cycles) agreed well with those measured with a chemiluminescence analyzer used in a field emission laboratory at a commercial laying hen site. It was also discovered that positive pressure air sampling/purging system seems more reliable than negative pressure system for the PMU. Care should be taken when directly applying commercial motor loggers to monitoring runtime of conventional capacitor start-capacitor run motors. Carbon dioxide balance method, based on modern metabolic rate data, seems to produce good estimation of building ventilation rate.

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