Instruments for measuring concentrations and emission rates of gases and particulates from animal feeding operations

This publication describes the operational characteristics of some commonly used instruments for measuring concentrations and emission rates of gases and particulates encountered in animal feeding operations (AFOs). Of special interest are the measurements of ammonia (NH_3), hydrogen sulfide (H_2S), and particulate matters (PM).

Integration of sophisticated analyzers and electronic devices, such as those listed in Table 1, Figures 1–10, may be used to measure multiple pollutants simultaneously and continuously. The mobile emission lab (MEL), Figure 11, with an estimated cost of $125,000, is an example of such integration. MEL is used by researchers and regulatory agencies throughout the country to measure ambient concentrations as well as emission rates of carbon dioxide (CO_2), NH_3, H_2S, and PM. Another example of this methodology is the custom-fabricated monitoring devices that comprise commercially available sensors that may also be used in air-quality monitoring. The portable monitoring unit (PMU), Figure 12, with an estimated cost of $3,000, was developed by Iowa State University researchers and is being used in a nationwide study of NH_3 and CO_2 emission from poultry facilities.

It should be noted that concentrations and emission rates are two different, although related, quantities. Concentrations measure the strength of the pollutant in the air or solution and have the unit of percent (%), parts per million (ppm), parts per billion (ppb), or parts per trillion (ppt). Emission rates, on the other hand, measure the magnitude of pollutant release from the source, and have the unit of weight of pollutant per animal or body weight (e.g., 500 kg or 1,100 lb) per unit of time (e.g., minute, hour, day, or year). The two are related by the air exchange rate through the source. Namely, emission rate is the product of concentration and ventilation rate.

The importance of quality data on ventilation rate in determining the emission rate cannot be overemphasized. Assumption and use of published fan performance data under commercial operation conditions can be off by 10 to 50 percent. A quick but less accurate way to check airflow rate of a ventilation fan is to measure the average air velocity (traverse) with an anemometer, Figure 13, through the cross-sectional area of the fan and multiply it by the cross-section area. A newly refined device, referred to as fan assessment numeration system (FANS), Figure 14, costs $10,000 (with trailer). The FANS allows users to calibrate actual fan airflow rate on site. The FANS has become a widely accepted and used instrument among researchers in AFO air emission studies.

The equation used to calculate emission rates based on concentration of the substance and local climatic conditions is given in Appendix A. Use of the equation also is illustrated by calculating NH_3 emission rate from a manure-belt laying hen house in central Iowa.

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Table 1. Instruments for measuring ammonia (NH₃), hydrogen sulfide (H₂S), and particulate matter (PM) concentrations

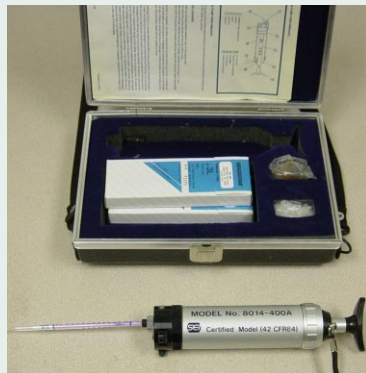| Instrument Type	Detection Limit[a]	Uncertainty[b]	Response Time[c]	Data Type	Degree of Maintenance	Portability	Power Required	Vulnerability or Immunity	Approximate Cost	Suitability
Ammonia (NH₃)										
Colorimetric tube (active or passive diffusion) (Fig. 1)	0.5 ppm	20–25% of reading	< 2 minutes	Snapshot or time integrated	N/A	Portable, easy to use	None		Tube: $5–6 Pump: $300	Indoor/outdoor ppm levels
Chem-cassette single point monitor (SPM) (Fig. 2)	3 ppm	20–25% of reading	> 10 seconds	Real time, continuous	Moderate	Fairly portable, weighs 15 lb	12 VDC, 110 VAC	Vulnerable to moisture interference	SPM: $7,000 Tape: $60–80 ea.	Indoor/outdoor ppm levels
Electro-chemical monitor (Fig. 3)	1 ppm	< 6% of reading	< 1 minute	Real time, continuous	Moderate	Portable, easy to use, weighs 0.5 lb	9 VDC	Vulnerable to sensor saturation from continuous NH₃ exposure	Base unit: $500 Sensor: $350	Indoor/outdoor ppm levels
Photo-acoustic multi-gas analyzer (Fig. 4)	0.2 ppm or lower	1% full scale	>13 s for single gas, and > 40 s 5 gases	Real time, continuous	Relatively low	Relatively portable, weighs 20 lb or less	110 VAC	May compensate for temperature, pressure, and moisture	$10,000 for NH₃ only $45,000 for five gases	Indoor/outdoor low-high ppm levels
Chemiluminescence analyzer (Fig. 5)	1 ppb	1% full scale	< 120 seconds	Real time, continuous	High	Not readily portable, weighs 60 lb	110 VAC	Immune to moisture interference	$17,000	Indoor/outdoor, ppb-ppm levels

Figure 1. Colorimetric tube (active or passive diffusion)

Figure 2. Chem-cassette single point monitor

Figure 3. Electro-chemical monitor

Figure 4. Photo-acoustic multi-gas analyzer

Figure 5. Chemiluminescence analyzer

Instrument Type	Detection Limit[a]	Uncertainty[b]	Response Time[c]	Data Type	Degree of Maintenance	Portability	Power Required	Vulnerability or Immunity	Approximate Cost	Suitability
Hydrogen Sulfide (H$_2$S)										
Colorimetric tube (active or passive diffusion) (Fig. 1)	0.5 ppm	20–25% of reading	< 2 minutes	Snapshot or time integrated	N/A	Portable, easy to use	None		Tube: $5–6 Pump: $300	Indoor/outdoor ppm levels
Chem-cassette single point monitor (SPM) (Fig. 2)	3 ppb	20–25% of reading	15 minutes	Real time, continuous	Moderate	Portable, weighs 15 lb	12 VDC, 110 VAC	Vulnerable to moisture interference	SPM: $7,000 Tape: $60–80 ea.	Indoor/outdoor ppb levels
Jerometer (Fig. 6)	3 ppb	1–2% full scale	< 30 seconds	Snapshot or real time, continuous	Moderate	Portable, easy to use, weighs 7 lb	12 VDC, 110 VAC		$8,000	Indoor/outdoor ppb-ppm levels
Pulsed fluorescence analyzer (trace level) (Fig. 7)	0.06–0.75 PPB, depending on operating mode	The larger of 1% reading or 1 ppb	80–320 seconds	Real time, continuous	Moderate	Not readily portable	110 VAC	Immune to moisture interference	$17,000	Indoor/outdoor, ppb-ppm levels
Particulate Matter (PM)										
Laser particle counter (LPC) (Fig. 8)	0.3 μm	10–15%	Immediate	Particle counts, not gravimetric	High when used in dusty conditions	Portable, easy to set up	12 VDC, 110 VAC	Contamination and hence instrument malfunction	$4,000 or more	Indoor/outdoor low PM levels
Filtration (Fig. 9)	Depends on balance used	> 10%	Variable	Time integrated	Low	Portable, easy to set up	12 VDC, 110 VAC	Care in sample handling and weighing	Pump kit: $800 Ready-to-use filters: $65/50	Indoor/outdoor, low-high PM levels
Tapered electronic oscillation microbalance (TEOM) (Fig. 10)	0.01 μg	5.0 μg/m^3 (10 min average) 1.5 μg/m^3 (1-hr average)	10–60 minutes, depending on precision	Real-time, continuous	High	Not readily portable	110 VAC	Clogging in dusty conditions	$18,000	Indoor/outdoor low-high PM levels

[a]Detection limit refers to the lowest level that the instrument is able to measure with the specified uncertainty.
[b]Uncertainty refers to the deviation of the measured value from the true value.
[c]Response time generally refers to the time needed for the instrument to register 90% or higher of the equilibrium value.
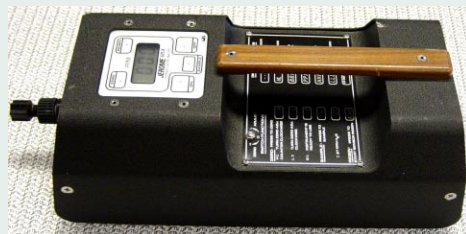

Figure 6. Jerometer

Figure 7. Pulsed fluorescence analyzer (trace level)

Figure 8. Laser particle counter

Figure 9. Filtration pump and filter

Figure 10. Tapered electronic oscillation microbalance

Figure 11. Mobile emission lab

Figure 12. Portable monitoring unit

Figure 13. Anemometer

Figure 14. Fan assessment numeration system

Appendix A. Equation and example of emission rate calculation

$$ER = Q \times (C_o - C_i) \times 10^{-6} \times \frac{W_m}{V_m} \times \frac{T_{std}}{T_a} \times \frac{P_a}{P_{std}}$$

where ER = emission rate, weight per unit time
  Q = ventilation or air exchange rate through the building or source at field temperature and barometric pressure conditions, volume per unit time
  C_i = concentration of the pollutant at inlet of the building or source, ppm
  C_o = concentration of the pollutant at outlet of the building or source, ppm
  W_m = molar weight of the pollutant at standard temperature (0 °C) and pressure (101.325 kPa) or STP, g/mole (e.g., 17 g/mole for NH_3)
  V_m = molar volume of the pollutant gas at STP, 22.4 L/mole
  T_{std} = standard temperature, 273.15 °K
  T_a = ambient temperature, (°C + 273.15) °K
  P_{std} = standard barometric pressure, 101.325 kPa
  P_a = ambient barometric pressure, kPa

Example. A manure-belt laying hen house located in central Iowa (elevation of 1,000 ft) contains 100,000 laying hens. The layer house is ventilated at 1.5 CFM per bird to maintain an indoor air temperature of 74 °F. Hourly average NH_3 concentration of incoming or fresh air and exhaust air is measured to be 0 and 4 ppm, respectively. Determine the hourly ammonia emission rate from the layer building.

Step 1. Building ventilation rate, Q
Q = 1.5 CFM/hen × 100,000 hens/bldg = 150,000 CFM/bldg
Converting Q from CFM to liter per hour by multiplying CFM value by 1,699,
Q = 150,000 CFM/bldg × 1,699 L/hr/CFM = 254,850,000 L/(hr-bldg)

Step 2. Absolute ambient temperature of the exhaust air, T_a
First, converting air temperature from Fahrenheit to Celsius by the following equation:
°C = (°F – 32)/1.8 = (74 – 32)/1.8 = 23.33
Then, the absolute temperature is determined as,
T_a = °C + 273.15 = 23.33 + 273.15 = 296.5 °K

Step 3. Ambient barometric pressure, P_a
At elevation of 1,000 ft above the sea, the nominal barometric pressure is 98 kPa, and is used in this calculation (if measured, use the actual value).

Step 4. Calculate NH_3 ER of the building by substituting the values into the ER equation:

$$ER = 254,850,000 \times (4 - 0) \times 10^{-6} \times \frac{17}{22.4} \times \frac{273.15}{296.5} \times \frac{98}{101.325} = 689 \; g /(hr\text{-}bldg)$$
$$= 1.52 \; lb/(hr\text{-}bldg)$$

Resources

For a list of research reports, ISU Extension publications, and links to current news regarding air quality and animal agriculture, please visit the Air Quality and Animal Agriculture Web page at http://www.extension.iastate.edu/airquality.