MEASUREMENT OF VENTILATION RATES USING A TRACER GAS

J. J. Leonard, J. R. Feddes, and J. B. McQuitty
Department of Agricultural Engineering, University of Alberta, Edmonton, Alta T6G 2H1.
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Use of a tracer gas to measure ventilation rates in animal housing was evaluated utilizing three methods. The gas used was sulphur hexafluoride which was detected by an electron-capture chromatograph. The three tracer methods involved whole-room constant-flow, whole-room decay, and fan-duct constant-flow techniques. Ventilation rates measured ranged from 70 L/sec to 1250 L/sec. When care was exercised in calibration of the detector and in the metering of tracer gas, results were obtained that were within 5% of hot-wire anemometer measurements. All methods depend on complete mixing of tracer gas with the air in the ventilated volume under consideration.

INTRODUCTION
In studies of the heat and moisture production of housed animals under commercial conditions, ventilation rates must be determined in order to carry out energy and moisture balances. Accurate measurement of ventilation rates is also required to determine the production rates of air contaminants such as carbon dioxide and ammonia. However, despite their importance, there is often considerable uncertainty associated with measurements of ventilation rates and a simpler, more reliable method would be desirable.

The difficulty of measuring ventilation rates arises from the fact that air velocities through inlets and outlets are variable and, despite the good intentions of designers, commercial buildings generally are not constructed in an 'airtight' fashion. One conventional approach to the problem has been to construct ducts, complete with flow-straightening vanes, downstream from exhaust fans. The air velocity profile of the duct cross-section, and hence the fan delivery, may then be determined in accordance with established fan-engineering practice (Jorgensen 1961) using pitot tube, hot wire, or thermistor anemometers (Feddes and McQuitty 1980). Although this method has proved satisfactory despite problems with dust laden sensors, the use of some form of tracer that could be injected into the ventilation airstream appeared to have potential as an alternative method.

Consequently, a study was undertaken with the objective of evaluating use of a tracer gas as a technique for measuring air exchange rates in animal housing. For this application sulphur hexafluoride (SF6) was selected as the tracer gas. This gas is colourless, odorless, and non-flammable. It is not a normal constituent of air and is sensitive to electron-capture detection by virtue of the six fluoride atoms in the molecule. In the concentrations used, it poses no threat to the health of either animals or operators (Kumar et al. 1979). The tracer gas was guaranteed by the supplier to be at least 99.8% pure.

INSTRUMENT
The instrument that was acquired for the purpose of tracer-gas monitoring was a detector chromatograph manufactured by A.I. Industrial, Cambridge, England. This instrument works on the basis of ion capture and is specifically designed for use with SF6. Although it may be run for short periods on a rechargeable battery pack, the instrument was invariably connected in this application to a 110-V supply which powered the detector and the vacuum pump that is part of the unit. Also mounted on the instrument chassis is a small cylinder containing argon, the carrier gas. The argon supply is controlled with a gas regulator which was set at the manufacturer’s specified pressure of 15 psi. Output is in the form of an analogue display on the front panel, or a 0- to 10-V analogue output that may be interfaced with a data logger or chart recorder. A multi-position switch on the front panel is used to select sensitivity ranges that give full scale readings from 0.1 to 2.0 ppm of SF6. Also located on the front panel is a bypass valve that controls the amount of air passing through the detector from the pump.

CALIBRATION
Initially, calibration was carried out using samples of air into which known quantities of tracer gas had been introduced by means of a multiple-dilution technique. A gas syringe was used to inject a small, measured quantity of SF6 into a known volume of air in a sealed container. After mixing, a measured quantity of the mixture was withdrawn and added to another container of air. This procedure could be repeated until any desired concentration was obtained. The final dilution stage was always carried out by injecting the penultimate mixture into a known volume of air contained in a Mylar bag. The instrument pump could then withdraw the calibration mixture from the bag at atmospheric pressure.

Whilst this method gave useable calibration curves, it was time consuming and subject to introduction of errors at each stage of dilution. The resulting scatter of calibration points led to the subsequent adoption of a technique using certified calibration mixtures. Three mixtures of SF6 in air were used having SF6 concentrations of 1 ppm, 0.66 ppm and 0.33 ppm. The use of certified mixtures gave excellent repeatability, and one-to-one correspondence between sample concentration and instrument reading could be obtained by adjustment of the bypass valve.

After zeroing the instrument in air, the 1-ppm mixture was used to adjust the span. This was done by adjusting the bypass flow rate until the meter reading was 1 ppm. With the instrument so adjusted it invariably gave true readings when checked with the other two calibration gases. All measurements taken fell within the range of concentrations covered by these gases.

MEASUREMENT SYSTEM
For a tracer gas to be used quantitatively in air-flow measurement, its rate of injection must be measured and controlled easily. Also, if several fans were to be monitored, provision must be made to deliver gas to all fan locations simultaneously. The system used to do this is illustrated schematically in Fig. 1. The flow of gas from the supply cylinder to each delivery line was controlled by precision needle valves and measured with soap-film me-
The sampling lines from each location terminated in a bank of solenoid valves. These were controlled by a microprocessor-based data logger which, together with patch-wiring, enabled sampling of any location at desired intervals, and for long enough periods to allow for transportation lag and instrument settling time. The sample air was drawn from each valve to the chromatograph for analysis before being vented into the surrounding air. The output from the instrument normally was recorded by the data logger at preset time intervals or, continuously for short periods, on a chart recorder.

METHODS

Tracer gas may be used in a number of ways to measure air flow (American Society of Heating, Refrigerating and Air-Conditioning, 1981). Three methods that have been used by these authors are described below:

(i) Whole-room, constant-flow: The tracer gas is injected at a constant rate at the air inlet and sampled at the air outlet from the room. If complete mixing of the air in the room is assumed, then the ventilation rate may be calculated from the diluted concentration using Eq. 1.

\[ Q = R/C \]  

where \( Q \) = air flow rate (L/sec); \( R \) = injection rate of SF\(_6\), (mL/sec); and \( C \) = measured concentration (mL/L).

In practice, unless high-capacity circulation fans are in operation in the ventilated space, the assumption of complete mixing may be hard to justify (Barber and Ogilvie 1982). In addition, both injection and ventilation rates must be held constant sufficiently long to allow the concentration of tracer gas to reach equilibrium in the ventilated room.

(ii) Whole-room decay: The tracer gas is injected at a high rate into the room where, again, complete mixing is assumed to occur. When the meter indicates a suitable initial concentration, injection is stopped and the concentration is monitored as it decays. If the ventilation rate is constant and mixing is complete, the decay of concentration with time, \( t \), may be described by the differential equation:

\[ \frac{dC}{dt} = C/Q/V \]  

where \( V \) = volume of the ventilated space (L).

The solution to Eq. 2 is:

\[ \ln(C/C_0) = -t/Q/V \]  

where \( C_0 \) = initial concentration of SF\(_6\) (ppm).

Thus, if the natural logarithm of fractional concentration, \( C/C_0 \), is plotted against time the result will be a straight line with a negative slope of \( Q/V \), which is the number of air changes per unit time. This method suffers from the same dependence on mixing as the previous method. Nevertheless, if air is sampled from a number of locations in the room to check on the mixing, good results may be obtained.

(iii) Fan-duct, constant-flow: This method is very similar to the whole room, constant-flow method except that the tracer gas is introduced at the exhaust fan inlets and air is sampled at the end of ducts constructed downstream from the fans. The flow rate through each fan is calculated using Eq. 1.

Although the third method requires injection and sampling lines for each individual fan, it was used by the authors in recent studies of animal environments on the basis that complete mixing of the tracer gas was more likely to occur, or could be encouraged more easily, in the limited confines of a duct rather than in an animal building as a whole.

Measurement of the concentration profile was carried out on a 16-point grid across the square duct cross-section. These measurements were facilitated greatly by the use of a two-pen chart recorder, one channel of which could be connected to a fan-speed sensor. Using this equipment, fan flow-rates were calibrated against fan speeds which were monitored continuously during heat and moisture balance experiments. Such calibrations are only valid if the static pressure differential between the inside and outside of the ventilated space remains constant.

RESULTS AND DISCUSSION

Tracer gas techniques were used first, by the authors, in an experiment on heat and moisture production of growing pigs (Feddes et al. 1983). In this experiment, pigs were housed in small (5-m x 2-m x 2.5-m) rooms supplied by a common conditioned-air duct. The ventilation rate of each room was determined by using several methods. With the first method, the air velocity profile in each exhaust duct was measured with a hot-wire anemome-
The ventilation rate was then determined from the mean velocity and the cross-sectional area of the duct.

Secondly, the whole-room constant-flow method was used with SF₆, being introduced at the air inlet grill and sampled at the end of the exhaust duct. Each room had a circulation fan to ensure mixing of the tracer gas, which was injected at approximately 0.1 mL/sec. Air was sampled in the exhaust ducts of each room which were also instrumented with thermistor anemometers. Steady and repeatable readings were obtained from the SF₆ meter in this application, indicating that complete mixing was taking place in the room. Mixing was also checked by sampling tracer gas concentrations throughout the room volume. These measurements were found to be uniform with those at the exhaust duct. There was no evidence of absorption of the tracer gas by the animals or the structure.

Thirdly the condition of the inlet and exhaust air were measured while only the wall-mounted strip heaters were providing heat to the rooms. The ventilation rate was then determined by carrying out a simple heat balance. As a further check, the air velocity profile at the inlet grill was used to calculate the inlet flow rate.

The ventilation rates derived from the last three methods were within 5% of each other but differed from that obtained using the first method by almost 20%. This suggested that, despite careful construction of the rooms, the positive-pressure ventilation system was giving rise to air leakage through openings other than the exhaust ducts. This was confirmed when the SF₆ was then introduced at the exhaust duct inlet and the flow rates derived from tracer gas measurements were found to be within 5–8% of those derived from the hot-wire anemometer.

The whole-room decay method also was utilized in the same experiment. The SF₆ was injected at the air inlet grill until the meter was indicating full scale. Injection then was stopped and the decay of gas concentration was monitored at the exhaust duct. Good agreement (5%) with the methods described above was achieved but, since the decay method is inherently time consuming, it is of limited value in continuous monitoring applications.

The range of ventilation rates measured using the above techniques was 60 L/sec to 85 L/sec.

In subsequent work on the monitoring of broiler barns (Feddes et al. 1983) complete mixing of the barn air could not be assumed. Consequently, in these cases, the fan-duct method was applied to the calibration of the exhaust fans. Mixing of tracer gas within the duct was checked by a 16-point sampling of tracer gas concentration across the duct. Mixing, however, was then found to be incomplete in the duct length used (3.5 m) when the tracer gas was injected at a single point. Complete mixing was obtained when injection was carried out through a manifold, situated upstream of the fan and having 16 ports arranged on a 100-mm-square grid. In all cases there was agreement within 5% between flow rates calculated using the tracer gas and those determined with a hot-wire ammeter. The flow rates measured ranged from 800 L/sec to 1250 L/sec.

Experience gained to date with the use of SF₆ as a tracer gas for measuring ventilation rates in animal housing suggests that it offers an acceptable alternative to hot-wire or heated-thermistor anemometer techniques. However, since the accuracy of the three tracer gas methods is highly dependent on the effectiveness with which the gas is mixed in air, the use of SF₆ to measure ventilation rates in commercial animal housing, where complete mixing is most unlikely, is of doubtful value unless the fan-duct, constant flow method is used. This method has been found to be convenient to use since, provided that the SF₆ is injected upstream of the fan through a suitable manifold, only one sampling location is necessary for measurement of the gas concentration in the downstream air flow. In comparison, a duct traverse involving multiple velocity readings is required with anemometer techniques. The method also may be adapted readily to continuous monitoring and recording of air flows through a fan or fans.

CONCLUSIONS

Sulphur hexafluoride tracer gas can be used as a convenient and accurate means of measuring ventilation flow rates in animal housing provided that the following points are observed:

1. The gas detector should be calibrated carefully over the desired operating range before use. The calibration should be checked from time to time during any extended periods of monitoring.

2. Provision must be made for the accurate metering of the tracer gas. This requires an accurate regulator on the supply bottle, precise metering valves that are not subject to thermal drift, and flow measuring devices that are accurate at the low flow rates used in these applications.

3. Care must be exercised in selecting injection and sampling points to ensure adequate mixing of the tracer gas, and sampling of air that is representative of the ventilated air space.

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REFERENCES


