Laboratory testing of humidity sensors for use in animal environments

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Erdebil, I. and Leonard, J.J. 1992. **Laboratory testing of humidity sensors for use in animal environments**. Can. Agric. Eng. **34**:267-271. Apparatus was built to allow humidity sensors to be exposed to environments in which both humidity and pollutant levels could be controlled. Humidity levels were varied by pumping air through saturated salt solutions and the pollutants used were ammonia and poultry dust. The apparatus was used to test two thin-film polymer sensors and one aluminum oxide sensor. Tests were carried out using three ammonia concentrations and three dust levels in a random factorial design. Humidity levels were varied slowly between approximately 33% RH and 85% RH and sensor outputs were compared with those from a calibrated dew-point hygrometer. The response of sensors to step changes in humidity levels also was evaluated. The thin-film sensors were not affected by pollutants but responded more slowly than the aluminum oxide sensor. All the sensors tested displayed similar accuracy ratings of ±6 to ±7% RH.

L'appareil a été conçu pour exposer plusieurs senseurs d'humidité à des milieux où la teneur en humidité et en polluants serait contrôlable. On a varié le degré d'humidité en pompant l'air travers des solutions salines saturées; l'ammoniac et les poussières de volaille ont servi de polluants. Deux senseurs à film mince de polymère et un senseur à oxyde d'aluminium ont ainsi été testés, avec trois concentrations d'ammoniac et trois concentrations de poussières, selon un plan expérimental factoriel. On a lentement varié les pourcentages d'humidité relative entre 33% hr et 85% HR environ, et les relevés ont été comparés à ceux d'un hygromètre à condensation étalonné. On a également mesuré la sensibilité des senseurs aux variations brusques d'humidité. Les senseurs à film mince n'étaient pas affectés par les polluants mais réagissaient plus lentement que le senseur à oxyde d'aluminium. La classe de précision était similaire pour tous les senseurs évalués (±6 à ±7% HR).

INTRODUCTION

Most environmental control systems for animal housing are based on temperature, although the need to control humidity, particularly at low temperatures, is well accepted (Agriculture Canada 1988). Ventilation control on the basis of temperature will, by itself, result in generally acceptable humidity levels when the outside temperature is above the heat deficit temperature. Below this temperature, moisture production by the housed animals requires active control of relative humidity (RH). Usually, such control is achieved by means of increased ventilation and supplemental heating. On the Canadian Prairies such humidity control may be required, ideally, for nearly two-thirds of the year (Zhang and Barber 1989).

A major obstacle to providing good humidity control has been the lack of inexpensive, electronic humidity sensors that will perform reliably in animal environments. Reliability problems have occurred in many RH sensors due to the air contaminants found in animal housing, principally dust and ammonia gas.

Since the levels of these contaminants vary from barn to barn and with time, there is a need for a controlled, reproducible laboratory procedure to evaluate the performance of humidity sensors in such environments. Such a procedure should simulate the barn environments and allow for the assessment of steady-state and dynamic performance of promising sensors.

The object of this work was to develop such a procedure and to use it in the evaluation of selected sensors. Accuracy, hysteresis, and response time were selected as objective measurements that would characterize sensor performance.

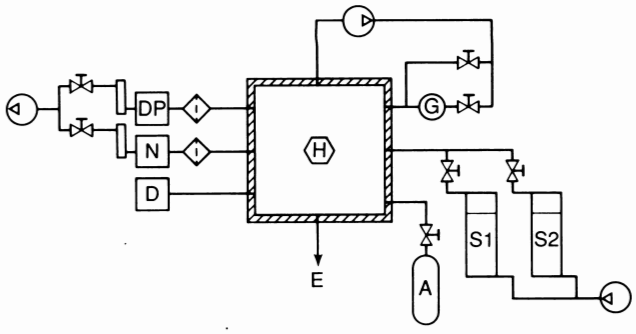
SENSORS

On the basis of a review of sensor technologies (Erdebil and Leonard 1988) and on device availability, one aluminum oxide (Al_2O_3) sensor (Model 135-Z, Ondyne Inc., Concord, CA) and two thin-film polymer sensors (Models HT220 and HT46, Rotronics Corp., Huntington, NY) were selected for evaluation. Both types of sensors depended on absorbed moisture changing the impedance of the hygroscopic material involved. In all cases the sensors were used in conjunction with power supply and signal-conditioning circuitry supplied by the manufacturers. Sensor elements were enclosed in protective screens but these could not be considered as dust filters. The sensors were used in accordance with the manufacturers' instructions but no pre-calibration or adjustments were carried out on them.

The outputs from the two thin film polymer sensors were 4 to 20 mA signals proportional to relative humidity. The Al_2O_3 system, on the other hand, produced a current output proportional to dewpoint temperature (^{o}C). For ease of recording, all output signals were converted to voltages.

TEST APPARATUS

The principal requirement of the testing system was to create an atmosphere that resembled typical barn environments and that could be changed in a controlled way to allow sensor testing. The apparatus developed for this has been described previously (Erdebil and Leonard 1988) and was based on a main test chamber into which moist air, dust, and ammonia could be introduced (Fig. 1). A much smaller chamber, con-



A – Ammonia cylinder
D – Dust analyzer
DP – Dew point hygrometer
N – Ammonia analyzer
G – Dust generator
H – Sensor under test
S1 – Salt solution
S2 – Salt solution
E – Exhaust

Rotameter
Pump
Valve
Filter (0.5μm)

Fig. 1. Schematic diagram of test apparatus.

tained within the main chamber was used in the evaluation of sensor response times as described below.

The main chamber was a cube made from 12.5 mm thick acrylic sheet and with sides of 0.5 m. The enclosed volume was large enough to hold all three sensors and associated circuitry while still allowing adequate volume for air mixing. The system was open in the sense that the chamber had a free exhaust. However, air was recirculated through the dust generator and this, together with moist air injection, provided complete mixing.

To provide moist air of known relative humidity, air was pumped into the chamber through saturated salt solutions (Wexler and Hasegawa 1954). Potassium chloride and magnesium chloride solutions were used to provide relative humidities of 85% and 33% respectively. These salts were chosen because their equilibrium relative humidity values approximately spanned the range of humidities found in monitoring studies of animal environments (Leonard et al. 1984; Clark and McQuitty 1985). Also, the equilibrium humidities associated with these solutions remain nearly constant over the full range of expected room temperatures (15-25°C). The humidity of the air in the chamber was monitored with a dewpoint hygrometer (Model 880, EG&G, Watertown, MA.). This was calibrated against a traceable standard and acted as the reference instrument for the system.

Ammonia was introduced into the chamber from an ammonia cylinder containing a 1.5% ammonia-in-air mixture and concentrations were measured using an infrared analyzer (Model 880, Rosemount Beckman Industrial Division, San Diego, CA). Flow was controlled by a needle valve placed after the cylinder pressure regulator. The needle valve was opened a small amount at 30-second intervals until the ammonia analyzer indicated the desired concentration. Once the desired ammonia levels were achieved, further adjustments seldom were needed. Since the system was not sealed, ammonia concentrations could be reduced easily by disconnecting the cylinder from the chamber or by closing the needle valve. Ammonia concentrations used for sensor testing ranged from 20 ppm to 40 ppm.

The dust used in sensor tests was collected from surfaces inside a broiler barn. The collected dust was sieved through a screen with 1.1 mm openings and then tumbled in a rolling cylinder for three hours to obtain a homogenous sample. The dust was introduced into the chamber using a small cyclone injection device. Dust was placed in the cyclone chamber and air from the test chamber was recirculated through the cyclone with a small diaphragm pump. As air passed through the cyclone, it entrained dust and then discharged back into the test chamber. Dust concentrations used were based on those observed in monitoring studies (Leonard et al. 1984; Clark and McQuitty 1985) and ranged approximately from 10 to 85 particles/mL with 99% of the particles being less than 5 μm in diameter.

Evaluation of the dynamic response of sensors required that they be exposed suddenly to either higher or lower humidity levels while maintaining desired pollution levels. The generation of these "step" changes was achieved by enclosing the sensor probes in a small (100 mL) chamber that could be isolated within the main chamber. A diaphragm pump with a capacity of 200 mL/s could draw air from the main chamber through the small chamber. This air could be trapped in the small chamber by means of a valve and the sensor allowed to stabilize. Meanwhile, the humidity in the main chamber could be changed while keeping contaminant levels constant. When the desired humidity had been reached, the valve was opened and the pump used to flood the small chamber with air at the new humidity level. Although not instantaneous, the change in RH was considered rapid enough to approximate a step change. Outputs from all the sensors under test and from the dewpoint hygrometer were recorded by an IBM compatible computer equipped with a data acquisition board (DA/M-100, Dycor Industrial Research, Edmonton, AB). This board had eight input channels with a multiplexed, eight-bit, analog-to-digital (A/D) converter.

METHOD

Sensors were cleaned with compressed air and test chambers were cleaned with a wet cloth prior to use and between tests. The sensors were allowed a "recovery period" of 12 hours after each test during which they were disconnected from their power supplies and exposed to clean air. The chambers were opened to clean room air for 12 hours after cleaning.

Tests carried out on the sensors included quasi-static, or calibration tests, as well as the dynamic tests described above. In the calibration tests, an atmosphere with desired pollution levels and a fixed humidity level was established in the main chamber. After the sensor under test had stabilized, the air inlet to the chamber was switched to the other saturated salt solution. Thus, air of a different humidity was drawn in and mixed with the air in the chamber. The humidity in the chamber changed as the mixing progressed and sensor outputs were monitored along with that from the dewpoint hygrometer. Preliminary tests had indicated that the air flow rate used (approximately 0.02 kg dry air per minute) gave adequate mixing and a rate of change of humidity that was

slow enough to avoid significant errors due to instrument response time.

In a typical calibration test, the sensors initially were exposed to clean air at the lower humidity level (approximately 33% RH). The humidity then was increased to the high level (approximately 85% RH) and returned to the low level to complete the cycle. At this point the desired contaminants were introduced and, after contaminant levels had stabilized for thirty minutes, the cycle was repeated. Sensors were kept at the high humidity level for thirty minutes before starting to decrease the humidity.

During a test run, sensor readings were taken every minute and recorded on diskette. Subsequently, the sensor output data (volts) were plotted against relative humidities calculated from the dewpoint hygrometer data. Values for accuracy rating and hysteresis were obtained from these calibration plots. A typical plot is shown in Fig. 2.

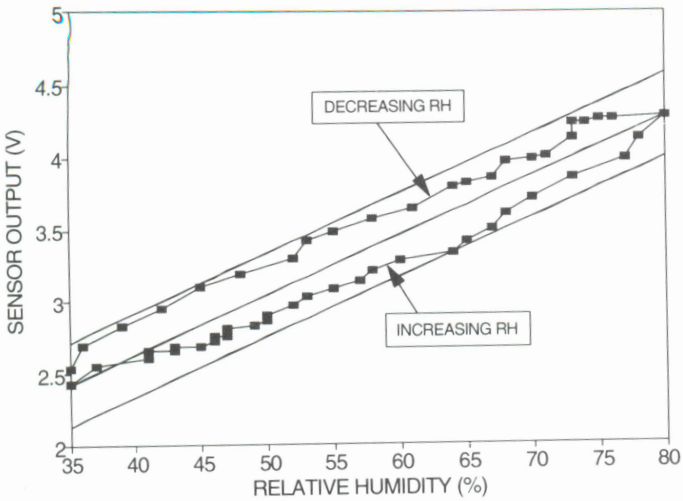


Fig. 2. Typical calibration curve.

For each calibration plot, a linear least-squares regression was carried out on the measured data. Accuracy rating was determined as the maximum deviation of the measured data from the regression line.

Hysteresis was evaluated at arbitrarily selected values of 50%, 60% and 70% RH. At each of these levels the hysteresis was simply the difference between sensor outputs obtained during increasing and decreasing phases of the calibration cycle.

The dynamic response tests were carried out separately from the calibration tests. Desired levels of pollutants and humidity were initially established in the main chamber. This air was circulated through the smaller chamber for five minutes before closing the valve that isolated the small chamber. The new relative humidity then was established in the main chamber. Data recording commenced as the valve was reopened and the recirculation pump started to draw new air through the small chamber. The pump was run for about three seconds and then stopped to allow turbulence to subside in the small chamber. Sensor readings were obtained at intervals of approximately one second. The test was terminated when the output reached 95% of the step input value. A typical plot of output values against time is shown in Fig. 3.

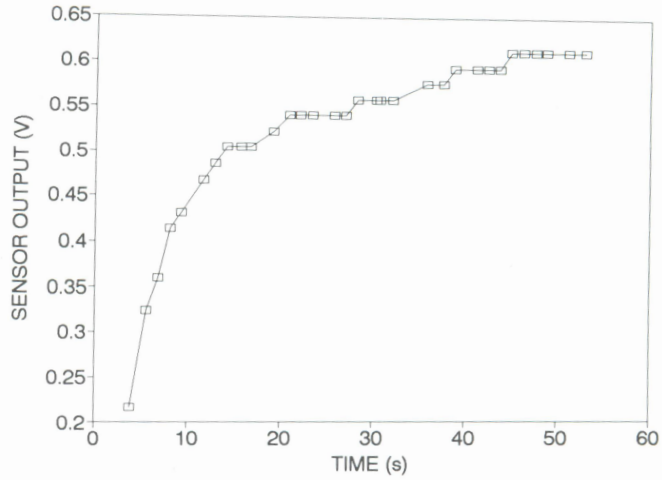


Fig. 3. Typical response to a step input.

EXPERIMENTAL DESIGN

The effects of the two pollutants (ammonia and dust) were considered simultaneously using randomized factorial designs for both the calibration and dynamic response experiments. Three levels of ammonia and dust were used to give nine possible combinations. Tests were carried out using each combination in a randomized order with two replicates giving a total of 18 test runs for each series. Ammonia concentrations used were 20, 30 and 40 ppm and the dust levels were 0.2, 10 and 85 particles/mL. The effects of the individual contaminants and their interactions were evaluated using analysis of variance.

RESULTS

The average values for accuracy rating and hysteresis for the three sensors tested are shown in Table I. Ammonia, dust, and their interaction had no statistically significant effect ($P = 0.05$) on the accuracy or hysteresis of either of the thin film sensors. The contaminants also showed no effect on the hysteresis of the Al_2O_3 sensor.However, the accuracy of the Al_2O_3 sensor was affected significantly ($P = 0.05$) by both contaminants and their interaction.

Table I. Average accuracy and hysteresis values in %RH

Sensor	Average Accuracy	Average Hysteresis		
		50% RH	60%RH	70%RH
Thin film 1	±6.28	5.94	6.72	5.94
Thin film 2	±7.11	6.83	6.89	6.89
Al_2O_3	±6.83	4.44	4.72	4.00

The data from each of the 18 dynamic response tests were subjected to curve fitting analyses in an attempt to define a function that could describe the general form of the sensor responses. The regression equation that gave the most consistent results across all tests was of the form:

$$Y = A - B/t \qquad (1)$$

where:

Y = sensor output (V),

t = time from step input, and

A, B = regression constants.

This equation gave an average R^2 value of 0.911 and the regression constants were positive for all tests. The constant A represents the final value of the sensor output (i.e., where t becomes large). The term B/t represents the sensor's resistance to instantaneous change.

Dividing both sides by A, Eq. 1 can be written in non-dimensional form as:

$$Y' = 1 - T/t \qquad (2)$$

where $Y' = Y/A$ and $T = B/A$. The response coefficient, T, has dimensions of time and provides a convenient measure of the sensor speed of response with higher values indicating slower response. Values of this response coefficient were calculated for each test and used as dependent variables in the statistical analysis of the sensor responses.

The analysis of variance indicated that, in all cases, pollutants did not have a significant effect (P = 0.05) on sensor response. Since response was not affected by pollutants, the response coefficients could be averaged for each sensor to provide equations representative of their response behaviour. These equations are shown in Table II.

Table II. Non-dimensional response equations

Sensor	Equation
Thin film 1	Y′=1-2.8/t
Thin film 2	Y′=1-2.7/t
Al_2O_3	Y′=1-3.6/t

DISCUSSION

The results of the calibration tests indicate that none of the sensors tested were highly accurate. The manufacturer of the two thin film sensors claimed an accuracy of ±2% RH whereas the measured accuracy of these sensors was around ±7% RH. This discrepancy could be due, at least in part, to the fact that the sensors were not fitted with screens or filters.

The manufacturer of the Al_2O_3 sensor claimed an accuracy of ±2°C (dewpoint) in the range -65°C to 20°C (dry bulb). At the test temperatures of about 20°C, this would imply accuracies of ±5% RH at 35% RH and ±10% RH at 85% RH respectively. This is comparable to the measured average accuracy of about ±7% RH.

The question of whether these measured accuracies are adequate for environment control in animal housing is debatable. However, if accuracies are known, at least control systems can be specified realistically and designed on a rational basis.

Although there was little difference in the accuracies of the sensors, the thin-film devices displayed immunity to contaminants at the levels used, whereas the Al_2O_3 device was affected. This has obvious implications for use of sensors in animal housing although the long-term performance of the sensors was not evaluated.

Even though it was susceptible to contaminants, the Al_2O_3 sensor did exhibit the least hysteresis of any of the sensors. In all cases, hysteresis could have been reduced and accuracy improved if the humidity had been allowed to stabilize at intermediate levels during the tests rather than varying continuously between the extreme values. However, the measured response of the sensors was quite rapid in comparison to the time taken for a test run. Thus, the effect of measuring at discrete, stabilized points would be small.

The method used to evaluate the dynamic response of the sensors proved satisfactory and the response coefficient, T, provided a convenient parameter, analogous to a time constant, to characterize the response. The measured, average values of T (which ranged from 2.75 to 3.65) indicate that the time for sensor outputs to come to within 95% of their final value was of the order of one minute. This would be quite adequate for most control applications in animal environments.

CONCLUSIONS

The following conclusions may be drawn from this study:

1. The apparatus and methods used provided a satisfactory means of evaluating humidity sensors under controlled conditions that approximated those found in animal housing.

2. Average accuracy ratings for the three sensors tested were similar (±6 to ±7% RH) and, in the case of the thin film sensors, were worse than the manufacturer's rating.

3. The thin film sensors were not affected by ammonia, dust or their interaction under the exposures used in these tests. However, the accuracy of the Al_2O_3 sensor was affected by the contaminants.

4. The dynamic response of the sensor could be represented by a non-dimensional equation of the form $Y' = 1 - T/t$. The average response coefficients, T, ranged from 2.75 to 3.65 with the thin film sensor showing faster response than the Al_2O_3 sensor.

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