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A RESISTANCE-HUMIDITY RELATIONSHIP FOR SENSORS OF THE DUNMORE TYPE

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SOMMAIRE

Les méthodes conventionnelles de la présentation graphique des caractéristiques résistance-humidité pour les détecteurs commerciaux du type Dunmore présentent quelques difficultés en ce qui concerne l'interpolation des observations expéri- mentales. Cette étude suggère une méthode grâce à laquelle les données de calibrage peuvent être représentées par une relation linéaire que l'on croit simplifier grandement à la fois l'établissement des courbes de calibrage et l'application pratique de ces données. En partant d'expériences effec- tuées avec des détecteurs vendus dans le commerce on s'est apercu que si la conductance du détecteur est mesurée par rapport à l'humidité relative sur des coordonnées logarith- miques l'isotherme qui en résulte est presque linéaire. Avec ce système l'interpolation linéaire entre les isothermes étab- lis le long de lignes de conductance fixes fournit des correc- tions de température précises pour l'intervalle des tempéra- tures allant de 0 à 70 °F, intervalle où la plupart des études ont été effectuées. Il permet une réduction substantielle du nombre de points requis pour le calibrage précis d'un détecteur particulier. À partir d'une relation semblable à celle susmentionnée on développe une équation qui décrit la con- ductance électrique de ce type de détecteur en fonction de l'humidité relative et de la température en utilisant quatre constantes empiriques de cellule.
27. A Resistance-humidity Relationship for Sensors of the Dunmore Type*

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ABSTRACT

Conventional methods of graphical presentation of resistance-humidity characteristics for commercial sensors of the Dunmore type have some shortcomings in regard to the interpolation of experimental observations. This paper suggests a method by which calibration data can be represented by a linear relationship which is believed to simplify greatly both the construction of calibration curves and the application of these data in practice.

From experiments with commercially available sensors it was found that if sensor conductance is plotted against relative humidity on logarithmic coordinates, the resulting isotherm is nearly linear. With this system, linear interpolation between established isotherms, along lines of fixed conductance, yields accurate temperature corrections over the temperature range from 0 to 70°F where most of the studies were conducted. It permits a substantial reduction in the number of points required for accurate calibration of an individual sensor.

From a relationship similar to that mentioned above an equation is developed that describes the electrical conductance of this type of sensor in terms of relative humidity and temperature using four empirical cell constants.

INTRODUCTION

The Dunmore-type humidity sensor consists basically of a substrate supporting a thin film of hygroscopic material and a pair of electrodes. The electrical resistance of the hygroscopic film varies greatly in response to changes in temperature and humidity. In general, therefore, it is necessary to find the relationship that exists between these variables by calibrating such a sensor before it can be used.

Calibration data (for these sensors) are usually presented as isotherms plotted on graphs that have resistance-relative humidity or current-relative humidity coordinates. The manufacturer supplies the same graph for all sensors of a given humidity range, with a correction value for each calibrated sensor. These graphs are suitable for normal use when the precision specified by the manufacturer (usually not better than ±1.5 per cent RH) is adequate. It has been found, however, that better precision is attainable with these sensors if special care is taken in their calibration and use. A single calibration point cannot completely define the resistance-temperature-humidity relationship, and when good precision is required, it is necessary to calibrate the sensors individually to account for the small deviations from the average, which some of them exhibit. To make precise calibration practical, it is important to keep the number

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of observations as small as possible and to present the results in a convenient form.

In this paper, a graphical method of presenting the data is discussed and equations showing the relationship between resistance, temperature, and humidity are presented.

**GRAPHICAL REPRESENTATION**

If the isotherms are plotted on logarithmic coordinates using the sensor conductance (or resistance) and the relative humidity as parameters, the resulting relationship is nearly linear in most cases over a resistance range of about 2 decades. Within this range, low- and high-range sensors display some curvature; as the range is extended, the departure from a straight line will increase significantly. A desirable characteristic of this method of plotting is that a fairly accurate isotherm can be found with only two points.

In order to aid the plotting of the data special graph paper has been used. Two scales are provided on the ordinate: a logarithmic scale covers a little more than two decades of conductance, and a current scale is matched to it. (The latter corresponds to the microampere scale used on many measuring instruments, and the current-conductance relationship will vary somewhat between instruments.) A logarithmic scale is provided on the abscissa and the relative humidity is plotted on it.

A number of sensors have been calibrated in a two-temperature recirculating atmosphere producer at the Prairie Regional Station. Some 70°F isotherms plotted on these coordinates are shown in Fig. 1; the abscissa covers a 10 to 1 range. Since the isotherms in the high humidity range are too steep when plotted on this paper, a 2 to 1 range is more suitable for sensors in the region above 40 per cent RH (Fig. 4).

When the observed temperature is different from the established isotherms, it is necessary to interpolate. With both conventional plots and the one described here, it is convenient to do this by linear proportion along the appropriate line of fixed conductance. If the corresponding relationship between temperature and humidity is not linear, an error will occur whose size depends on the separation of the isotherms and the degree of nonlinearity. The dependability of this procedure for conventional and logarithmic plots is illustrated in Fig. 2, where data have been plotted for

![Fig. 1. Plot of 70°F isotherms on logarithmic coordinates.](image-url)
Fig. 2. Plots of midrange relative humidity, on linear and logarithmic coordinates, vs sensor temperature.

Fig. 3. Plot of isotherm slopes vs midrange relative humidity.
several sensors. These graphs suggest that for limited ranges of temperature, the linear proportion interpolation is suitable for both methods of plotting. In this and all other cases in this paper the relative humidity for temperatures below 32°F is based on the vapor pressure over subcooled water rather than ice.

This method of plotting data provides a basis for the systematic comparison of sensors. For example, cell-to-cell variation is illustrated in Fig. 3, where the slopes of a number of 70°F isotherms have been plotted against their midrange (1.0 μmho) relative humidities. Generally, the slopes of sensors in the same humidity range are nearly equal and the variation with midrange relative humidity follows a definite pattern. In some cases, sensors have shifted out of their original ranges. Some of these have followed the trend line and, as far as the slope is concerned, can legitimately be identified with the sensors in the region to which they have moved. Others have moved out of their original ranges and conform neither to their original slopes nor to those of their new region. This suggests that although it is probable that sensor characteristics will agree closely with standard calibration curves, there is no guarantee that this will be so, and calibration at a number of points is necessary to ensure a high degree of precision.

**REPRESENTATION WITH EQUATIONS**

For most purposes, graphical representation is likely to be preferred. In some instances, however, an equation which relates the variables may be useful. Such equations can be formulated by an extension of the foregoing analysis.

Because the present discussion falls into the same category, it may be useful to mention some of the published results of studies of the effect of temperature and moisture on electrical conductivity, in hydrophilic and other materials. In much of the work on organic materials, the relationship between temperature and electrical conductance follows the form of the Arrhenius equation. Relationships between moisture content and electrical conductivity have been proposed for hygroscopic, fibrous materials and for several inorganic materials including glass and porcelain. As a result of the investigation reported in Ref. 7

\[
\log \left( \frac{i}{i_0} \right) = \alpha m \quad (2)
\]

was found to relate the current flow \( i \) and moisture content \( m \). Work of this type has been done with chromium films and anodized aluminum. One of the most extensively investigated organic materials is wood, much work having been done to determine the relationship between moisture content and electrical conductivity.

When isotherms are plotted on logarithmic coordinates, it is apparent that they are not parallel and, if extrapolated, will intersect one another (Fig. 4). It is not suggested that the extrapolated isotherms constitute a valid representation of the conductance-humidity relationships in the conductance region above 10 micromhos. The extrapolation is done only for purposes of the analysis. Although it is not possible to locate the intersection points very precisely, it seems practical to assume that all the isotherms for a given sensor intersect at the same point. The value of the abscissa corresponding to this point will be referred to as \( A \), and the value of the ordinate, as \( C_0 \).

The analysis is more conveniently carried out if the difference, \( \log A - \log \phi \) or \( \log (A/\phi) \).
FIG. 5. (a). Plot of the same isotherms shown in Fig. 4, using \(120/\phi\) instead of \(\phi\). Coordinates are logarithmic.

(b) Plot of isotherm slopes as \(10^3/T\) using logarithmic coordinates and linear coordinates.

\(120/\phi = \frac{A}{\phi}\)

The isotherm equation is

\[
\log C = \log C_0 + S \log (A/\phi)
\]

or

\[
\log \frac{C}{C_0} = S \log (A/\phi)
\]

The isotherm slope \(S\) is a function of the temperature. In Fig. 5(b) the slope is plotted against the reciprocal of the absolute temperature, using two different coordinate systems. In one case logarithmic coordinates are used, in the other, linear coordinates.

In the first instance, the slope-intercept equation is

\[
\log S = \log K + a \log (1/T)
\]

or

\[
S = K(1/T)^a
\]

The final equation is

\[
\log \frac{C}{C_0} = K(1/T)^a \log (A/\phi)
\]

In the second case the slope intercept equation is

\[
S = D + (b/T)
\]

The final equation is

\[
\log \left(\frac{C}{C_0}\right) = (D + (b/T)) \log (A/\phi)
\]

These equations each contain four unknown constants. Consequently, at least four experimental points are required for complete calibration of a sensor, unless it can be shown that the constants are not all independent of one another, or that one or more can be evaluated from fundamental considerations.

In Figs. 6 and 7 the experimental values corresponding to Eqs. (5) and (6) are plotted for two of the sensors. Values of \(A\) and \(a\) are found by graphical means, and the abscissa values are calculated. The values of \(A\) are found to vary from just over 100 for high-range sensors to values exceeding 1000 for low-range sensors.

CONCLUSION

In developing the plotting technique and the equations, it was assumed that linear isotherms result from a logarithmic plot of sensor conductance and relative humidity. For sensors operating in the region below 80 per cent RH, this is generally correct to better than 0.5 per cent RH over a range of about two decades of conductance. For sensors in a higher humidity range, a significant amount of curvature exists, with the result that the calibration data may depart by as much as 1.5 per cent RH from the straight line of best fit. Part of this deviation will be caused by scatter of points due to hysteresis. Similarly, in applying temperature corrections, an error will result if the relationship used is not linear. Three different functions of temperature have been used in this paper. All appear to fit the data with a degree of precision that is consistent with the precision of the calibration data. The apparent linearity of all the relation-
Fig. 6. Plots of the values of $\log C$ calculated using the two equations developed in Figs. 4 and 5. The equations are

$$\log C = 4.43 + \left(28.2 - \frac{23000}{T}\right) \log \frac{120}{\phi}$$

and

$$\log C = 4.43 - 2.89\left(\frac{10^3}{T}\right)^{0.41} \log \left(\frac{120}{\phi}\right)$$

Fig. 7. (a) Plot of isotherm slopes vs $10^3/T$ on logarithmic and linear coordinates. The midrange relative humidity at $70^\circ F$ for this sensor is 15 per cent.

(b) Plots of the two equations for this sensor.
This method of plotting calibration data is useful when sensors are to be used for research and will therefore be recalibrated frequently. Because of their near linearity, a reliable isotherm can be established with two accurate calibration points. With two isotherms that differ by $30^\circ$ or $40^\circ F$, linear interpolation between the isotherms and limited extrapolation beyond them can be expected to provide a good degree of precision in relating sensor conductance or resistance to relative humidity over the normal temperature range. With the information provided by two such isotherms, individual deviations of sensors from the average will be taken into account. In subsequent checks of the calibration, a single value will be sufficient to reestablish the conductance-humidity relationship unless a large shift has occurred, in which case a more complete recalibration will be required.

In developing an equation for a sensor, two well-spaced isotherms are required. The constants $A$ and $C$ can be found by locating their point of intersection. The slope equation can then be calculated to complete the sensor equation. If shifts in the calibration occur, a corresponding change must be made in the equation.

**SYMBOLS**

- $a = \text{constant, dimensionless}$
- $A = \text{constant, relative humidity}$
- $b = \text{constant, } ^\circ R$
- $C = \text{electrical conductance, micromhos}$
- $D = \text{constant, dimensionless}$
- $K = \text{constant, } ^\circ R$
- $p = \text{vapor pressure at temperature } t$
- $p_s = \text{vapor pressure at saturation at temperature } t$
- $T = \text{temperature, } ^\circ R \text{ (Rankine)}$
- $\phi = \text{relative humidity, } p/p_s$

**References**