rotronic

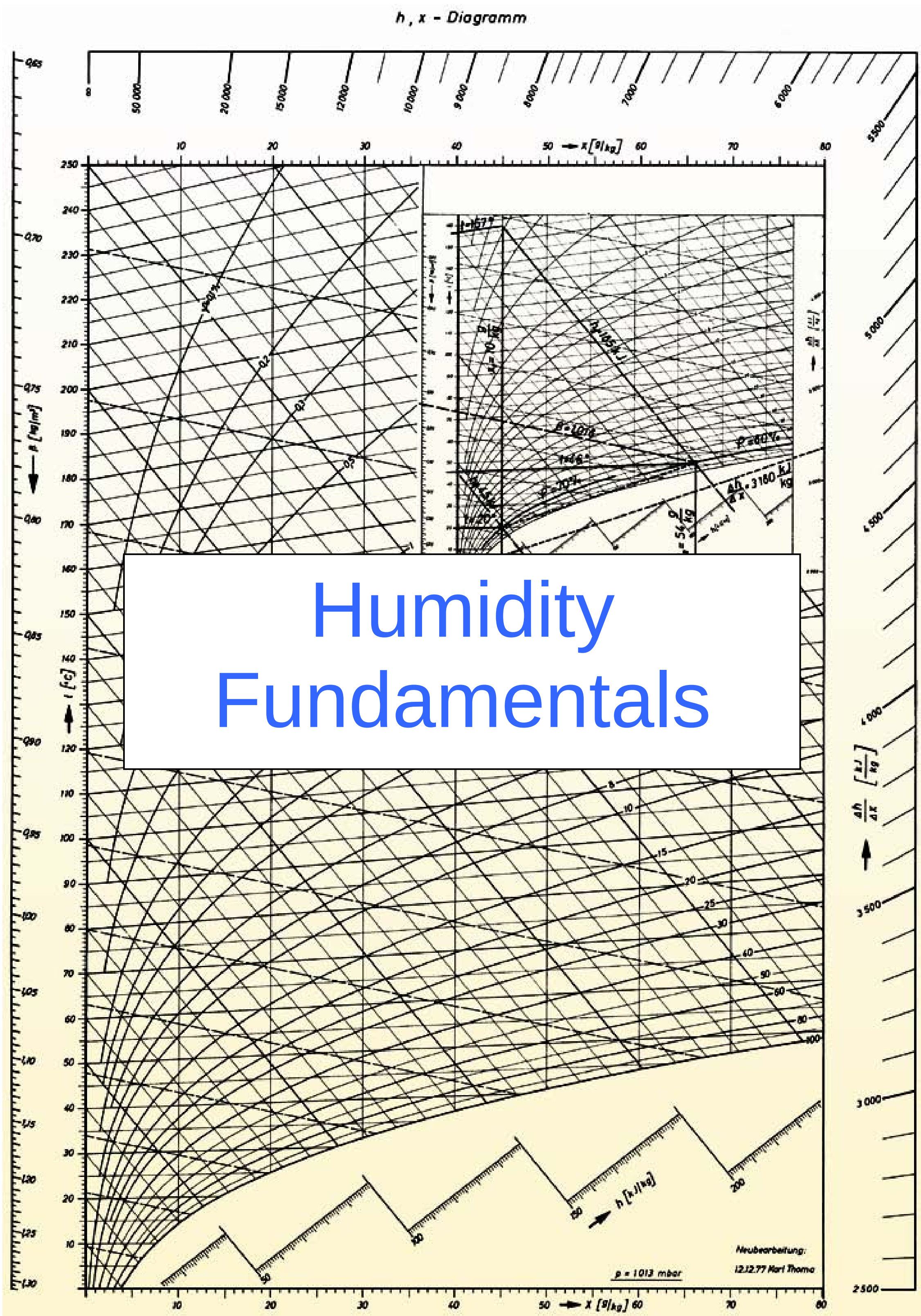
LEADING IN HUMIDITY MEASUREMENT

The Rotronic Humidity Handbook

All you never wanted to know about Humidity and didn't want to ask!

Rotronic Instrument Corp.
www.rotronic-usa.com
12/2005

Humidity Fundamentals



Humidity Fundamentals

Relative Humidity, Pressure and Temperature

Foreword

This technical note reviews the basic laws of physics that govern relative humidity.

Within a temperature range of -50 to 150°C and at pressures not in excess of 1000 kPa, water vapor practically behaves like an ideal gas. Examples are provided to illustrate the influence of temperature and pressure on relative humidity and to show how to convert relative humidity into dew point and absolute humidity.

This note is largely inspired from the textbook Chemistry by Theodore L. Brown and H. Eugene LeMay, JR. (Prentice-Hall, 1977).

Ideal Gas Laws

By definition, an ideal gas follows the following laws:

Boyle's Law: this law states that at constant temperature, the product of the volume and pressure of a given amount of gas is a constant.

$$P \times V = \text{constant}$$

The value of the constant depends on how much gas is in the volume.

Charles's Law: this law states that at constant pressure, the volume of a given quantity of gas is proportional to absolute temperature (°K).

$$V = q \times T$$

where q is a proportionality constant that depends on the quantity of gas.

Charles's law can be stated in another form: at constant volume, the pressure of a given quantity of gas is proportional to absolute temperature.

$$P = j \times T$$

where j is a proportionality constant that depends on the particular sample of gas and its volume.

Note: to convert temperature in °C into absolute temperature in °K, add the constant 273.15.

Dalton's Law of Partial Pressures: this law states that that the total pressure of a mixture of gases is equal to the sum of the pressures that each gas would exert if it were present alone.

$$P_t = P_1 + P_2 + P_3 + ...$$

where P_1, P_2, etc., are the partial pressures of gases 1, 2, etc.

Avogadro's Hypothesis: this hypothesis states that equal volumes of gases at the same temperature and pressure contain equal numbers of molecules. For instance, one liter of any ideal gas at a temperature of 0°C and a pressure of 101.3 kPa, contains 2.688 x 10^{22} molecules.

Note: the temperature of 0°C and pressure of 101.3 kPa is the standard temperature and pressure condition or STP.

Volume of a Mole of Gas at STP:

A mole of any element is defined as the amount of that element that contains the same number of molecules (or atoms in the case of a mono atomic element) as exactly 12 g of ^{12}C (Carbon 12).

It has been experimentally determined that the number of atoms in this quantity of ^{12}C is 6.022 x 10^{23}. This number is called Avogadro's number.

As one liter of gas, at STP, contains 2.688 x 10^{22} molecules (or atoms in the case of a mono atomic gas), it follows that a mole of gas (6.022 x 10^{23} molecules) occupies a volume of 22.4 l, at STP.

Ideal Gas Law: this law states that the product of volume and pressure of a given amount of gas is proportional to absolute temperature.

$$P \times V = n \times R \times T$$

where n is the number of moles of gas and R the molar gas constant.

The constant R is equal to:

0.08206 atm x liter/°K x mole.

8.30928 Pa x m^3/°K x mole

Mole Fractions and Partial Pressure

The composition of one mole of a gas mixture can be expressed in terms of the mole fractions of its components. The mole fraction of a particular component is defined as the total number of moles of the component divided by the total number of moles of all the components. From this definition, it follows that the sum of all mole fractions is equal to one. Taking dry air near sea level as an example, the mole fractions of the three main components are as follows:

Nitrogen	: 0.78084
Oxygen	: 0.20948
Carbon Dioxide	: 0.00954

If P_t is the total pressure of a gas mixture and n_1, n_2, etc. the mole fractions of its components, it follows that:

$$P_t = P_t \times (n_1 + n_2 + ...) \text{ and}$$
$$P_t = P_t \times n_1 + P_t \times n_2 + ...$$

where $P_t \times n_1$, $P_t \times n_2$, etc. are the partial pressures of components 1, 2, etc.

The above equation is another form of Dalton's law.

Effect of a Change In Pressure

Dalton's law states that the total pressure of a gas mixture is equal to the sum of the partial pressures of its components. From this, it was derived that the partial pressure of a component is equal to the product of the total pressure times the mole fraction of the component.

Therefore, a change in the total pressure of a gas mixture, at constant composition, results in the same change in the partial pressure of each component. For instance, doubling the total pressure of a gas mixture results in doubling the partial pressure of each component.

Real Gases

Real gases fail to obey the laws of ideal gases to greater or lesser degree. The van der Waals equation corrects the equation established for ideal gases:

$$(P + an^2/V^2)(V - nb) = nRT$$

where a and b are constants that depend on the nature of the gas.

From the van der Waals equation, it is apparent that a real gas tends to behave like an ideal gas when the volume of gas is large.

The constant b of most common gases is less than. At STP, the number of moles n is equal to one when the volume V equals 22.4 l. Therefore, most real gases behave almost like ideal gases when placed in a large volume at moderate pressure (1000 kPa or less).

Vapor Pressure Above a Liquid

Molecules in a liquid are closer one to another than they are in a gas. Therefore, intermolecular forces are stronger than in a gas. For a liquid to vaporize, the intermolecular forces have to be overcome by the kinetic energy of the molecules.

If a liquid is placed in a closed container, the particles entering the vapor phase cannot escape. In their random motion, many particles strike the liquid and are recaptured by intermolecular forces. Thus two processes occur simultaneously: evaporation and condensation.

The rate of evaporation increases as temperature increases. This is so because an increase in temperature corresponds to an increase in the kinetic energy of molecules. At the same time, the rate of condensation increases as the number of particles in the vapor phase increases: more molecules strike the surface of the liquid. When these two processes become equal, the number of particles and, therefore, the pressure in the vapor phase, becomes stabilized.

The value of the equilibrium vapor pressure depends on the attractive forces between particles of the liquid and on the temperature of the liquid. Vapor pressure above a liquid increases with increasing temperature.

The presence of gases other than vapor above a liquid does not affect the kinetic energy of molecules inside or outside the liquid and does not affect the magnitude of the intermolecular forces in the liquid. Therefore, vapor pressure above a liquid does not depend on the total pressure above the liquid.

Vapor Pressure of Water

The vapor pressure of water, or saturation vapor pressure, increases strongly with increasing temperature:

Temperature (°C)	Water Vapor Pressure (kPa)
0	0.61
10	1.23
20	2.34
30	4.24
40	7.37
50	12.33
60	19.92
70	31.18
80	47.34
90	70.11
100	101.33 = 1 atm

Vapor Pressure of Water Mixed with Another Substance

If water is mixed with a non volatile substance to form a non electrolyte solution, the vapor pressure is proportional to the mole fraction of water in the solution (Raoult's law). Because of the electrostatic attraction between ions, electrolyte solutions do not exactly follow Raoult's law.

This can be explained as follows:

At a given temperature, the kinetic energy of all particles (molecules, ions) in the solution is the same. Essentially the same number of particles are at the surface in both the solution and pure water. However, in the case of the solution, only the water molecules can escape from the solution. As these represent only a fraction of the total number of particles present at the surface, vapor pressure is lowered.

The following table provides a few examples of saturated salt solutions (electrolyte solutions) at a temperature of 25°C:

Solute	Vapor pressure (kPa)	Pressure Ratio Solution/Pure Water
LiCL	0.358	11.3 %
MgCl	1.039	32.8 %
NaCl	2.387	75.3 %
KCl	2.673	84.3 %

Vapor Pressure Above Ice

When water freezes, the molecules assume a structure which permits the maximum number of hydrogen-bonding interactions between molecules. Because this structure has large hexagonal holes, ice is more open and less dense than liquid water. As hydrogen-bonding is stronger in ice than in liquid water, it follows that the inter-molecular attraction forces are the strongest in ice. For that reason, vapor pressure above ice is less than the vapor pressure above liquid water.

Temp (°C)	Vapor Pressure Liquid (kPa)	Vapor Pressure Ice (kPa)	Ratio Ice/Liq.
0	0.611	0.611	1.00
-5	0.422	0.402	0.95
-10	0.287	0.260	0.91
-15	0.191	0.165	0.86
-20	0.126	0.103	0.82
-25	0.081	0.064	0.78
-30	0.049	0.037	0.75

Definitions of Humidity

Vapor Concentration (Absolute Humidity)

The vapor concentration or absolute humidity of a mixture of water vapor and dry air is defined as the ratio of the mass of water vapor M_w to the volume V occupied by the mixture.

$D_v = M_w / V$, expressed in grams/m^3 or in grains/cu ft

The value of D_v can be derived as follows from the equation PV = nRT

$M_w = n_w \times m_w$, where :

n_w = number of moles of water vapor present in the volume V
m_w = molecular mass of water

$D_v = M_w / V = n_w \times m_w / V = m_w \times p / RT$, where:

m_w = 18.016 gram
p = partial pressure of water vapor [Pa]
R = 8.31436 Pa x m3 / °K x mole
T = temperature of the gas mixture in °K

$D_v = p / 0.4615 \times T$ [g / m^3]

1 gr (grain) = 0.0648 g (gram)
1 cu ft = 0.0283168 m^3

D_v [gr / cu ft] = 0.437 x D_v [g / m^3]

Specific Humidity

Specific humidity is the ratio of the mass M_w of water vapor to the mass ($M_w + M_a$) of moist air.

$Q = M_w / (M_w + M_a)$

$Q = p\, m_w / (p\, m_w + (P_b - p)\, m_a)$

$Q = 1000\, p / (1.6078\, P_b - 0.6078\, p)$ [g / kg]

1 gr (grain) = 0.0648 g (gram)
1 lb = 0.4535923 kg

Q [gr / lb] = 7 x Q [g / kg]

Mixing Ratio

The mixing ratio r of moist air is the ratio of the mass M_w of water vapor to the mass M_a of dry air with which the water vapor is associated:

$r = M_w / M_a$

$M_w = n_w \times m_w = m_w \times p V / RT$
$M_a = n_a \times m_a = m_a \times p_a V / RT = m_a \times (P_b - p) V / RT$, where:

n_w = number of moles of water vapor present in the volume V

n_a = number of moles of dry air present in the volume V
m_w = 18.016 gram
m_a = 28.966 gram
p = partial pressure of water vapor [Pa]
p_a = partial pressure of dry air [Pa]
P_b = total or barometric pressure [Pa]
R = 8.31436 Pa x m3 / °K x mole
T = temperature of the gas mixture in °K
V = volume occupied by the air – water vapor mixture

$r = m_w\, p / m_a\, (P_b - p)$

$r = 621.97 \times p / (P_b - p)$ [g / kg]

1 gr (grain) = 0.0648 g (gram)
1 lb = 0.4535923 kg

r [gr / lb] = 7 x r [g / kg]

Volume Mixing Ratio

The volume mixing ratio is the ratio of number of moles of water vapor n_w to the number of moles of dry air n_a with which the water vapor is associated. This usually expressed in terms of parts per million:

$PPMv = 10^6 \times n_w / n_a$

$n_w = p\, V / RT$
$n_a = p_a\, V / RT = m_a \times (P_b - p)\, V / RT$, where:

p = partial pressure of water vapor [Pa]
p_a = partial pressure of dry air [Pa]
P_b = total or barometric pressure [Pa]
R = 8.31436 Pa x m3 / °K x mole
T = temperature of the gas mixture in °K
V = volume occupied by the air – water vapor mixture

$PPMv = 10^6 \times p / (P_b - p)$

Relative Humidity

Relative humidity is the ratio of two pressures: **$\%RH = 100 \times p/p_S$**

where p is the actual partial pressure of the water vapor present in the ambient and p_S the saturation pressure of water at the temperature of the ambient.

Relative humidity sensors are usually calibrated at normal room temperature (well above freezing). Consequently, it generally accepted that this type of sensor indicates relative humidity with respect to water at all temperatures (including below freezing).

As already noted, ice produces a lower vapor pressure than liquid water. Therefore, when ice is present, saturation occurs at a relative humidity of less than 100 %. For instance, a humidity reading of 75 %RH at a temperature of -30°C, corresponds to saturation above ice.

Dew Point and Frost Point Temperature

The dew point temperature of moist air at temperature T, pressure P_b and mixing ratio r is the temperature to which the air must be cooled in order to be saturated with respect to water (liquid).

The frost point temperature of moist air at temperature T, pressure P_b and mixing ratio r is the temperature to which the air must be cooled in order to be saturated with respect to ice.

Wet Bulb Temperature

The wet bulb temperature of moist air at pressure P_b, temperature T and mixing ratio r is the temperature which the air assumes when water is introduced gradually by infinitesimal amounts at the current temperature and evaporated into the air by an adiabatic process at constant pressure until saturation is reached.

Effect of Temperature and Total Pressure on Vapor Pressure

When considering the effect of temperature and pressure on the partial pressure of vapor, it is essential to make a difference between the following situations:

- saturation (liquid or ice) vs. no saturation (vapor only);
- closed container of fixed volume vs. open space.

Saturation:

The partial pressure of vapor is equal to the saturation pressure and its value depends only on temperature. There is no difference between the situation in an open environment and that in a closed container.

No Saturation

Water vapor behaves almost like an ideal gas and the following equation applies regarding the partial pressure of vapor:

$$p \times V = n \times R \times T$$

a) In an open space: the volume V occupied by vapor is free to expand. Therefore, the partial pressure p is not affected by temperature. The partial pressure p can vary only if n varies (vapor is being added or removed) or if the total pressure varies (Dalton's law of partial pressures). For instance, total pressure drops with increasing altitude and this results in a decrease of the partial pressure of vapor.

b) In a closed container of fixed volume: vapor occupies the entire volume of the container and this volume is constant. Therefore, the partial pressure p can vary only if there is a change in absolute temperature (degrees K) or a change in the amount of vapor. The partial pressure p does not vary with a change in total pressure.

Effect of Temperature and Pressure on %RH

Saturation vapor pressure depends only on temperature. There is no effect of total pressure and there is no difference between the situation in an open space and that in a closed container.

From the above it follows that:

a) in an open space, at constant moisture level and temperature, %RH is directly proportional to the total pressure. However, the value of %RH is limited to 100% as p cannot be greater than p_S.

b) in an open space, at constant moisture level and pressure, %RH decreases strongly as temperature increases.

c) in a closed container of fixed volume, %RH decreases as temperature increases, however not quite as strongly as in the situation of the open space.

Examples

a) Office Building

For practical purposes, an office building can be considered as an open environment. A localized increase in temperature created by a heater or an office machine, does not modify the value of the partial pressure of water vapor. Therefore, the local vapor pressure is the same as elsewhere in the building. However, the saturation vapor pressure is locally increased. Consequently, relative humidity in the immediate vicinity of the heat source is lowered.

If we assume that elsewhere in the building temperature is 25°C and relative humidity 50 %, a localized increase of temperature to 30°C lowers relative humidity as follows:

p_S at 25°C = 3.17 kPa
p_S at 30°C = 4.24 kPa

p = 0.5 x 3.17 kPa = 1.585 kPa, corresponding to 50 %RH

Localized %RH = 100 x 1.585/4.24 = 37.4%

b) Dew on a Chilled Mirror

If the temperature of a mirror is lowered to precisely the value that makes dew appear at the surface of the mirror, the value of the mirror temperature is called dew point. Using the previous example, the dew point corresponding to a condition of 50 %RH and 25°C can be found as follows:

p_S at 25°C = 3.17 kPa
p = 0.5 x 3.17 kPa = 1.585 kPa, corresponding to 50 %RH

If there is equilibrium between the dew on the mirror and the environment, it follows that p_S at the temperature of the chilled mirror must be equal to the vapor pressure p. Based on a simple interpolation of the values of the saturation vapor tables, we find that a value of p_S of 1.585 kPa corresponds to a temperature of 13.8°C. This temperature is the dew point.

This example shows that converting relative humidity into dew point and vice versa requires the use of a thermometer and saturation vapor tables.

c) Compression in a Closed Chamber

If the total pressure inside a closed chamber is increased from one to one and a half atmospheres and temperature is maintained constant, the partial pressure of water vapor is increased 1.5 times. Because temperature is maintained constant, the saturation pressure p_S is not changed. If we assume that we had a condition of 50 %RH and 25°C before the compression, the condition after compression is 75 %RH and 25°C.

d) Injection of a Dry Gas in a Closed Chamber

If, for instance, dry nitrogen is injected in a closed chamber where there is already air at a condition of 50 %RH and temperature is maintained constant, total pressure in the chamber increases. However, the partial water vapor pressure p remains constant because the mole fraction of water vapor in the chamber decreases by an amount that exactly balances the increase in total pressure (see Dalton's law). Because temperature is maintained constant, the saturation vapor pressure p_S is also unchanged. Therefore, relative humidity stays at 50 % in spite of the fact that a dry gas was injected in the chamber.

Relative Humidity Calibration

Method of Calibration

A frequent method of calibrating a relative humidity instrument is to place the humidity sensor in a closed container. By putting a known solution of water and another substance inside the container, a known humidity is established at equilibrium. This humidity value is used to provide a reference against which the instrument can be adjusted or calibrated.

Temperature Stability

Obtaining equilibrium conditions is one of the most critical requirements of the method. This means that there should be no difference of temperature between the humidity sensor, the solution and the head space above the solution. Unstable temperature during calibration will not permit this. A temperature stability of 0.02°C/min or better is required during the calibration process for the method to be accurate.

Temperature of Calibration

The relative humidity values generated by the different solutions used to the purpose of calibration, are affected by temperature. Therefore, a correction must be made for the temperature of calibration. However, no correction is required for the effect of temperature on the total pressure inside the calibration container.

The temperature of calibration may also be restricted by the design of the instrument. For instance, an instrument that provides a compensation for the effect of temperature on the humidity sensor does so by assuming that the temperature of calibration is always the same. In that case, the manufacturer provides a recommendation as to the range of calibration temperature that result in the best overall accuracy for the instrument.

Altitude

Because vapor pressure above a solution is not affected by total pressure, no correction is required for altitude.

Influence of Temperature Variations on Solutions

A saturated solution results of the dynamic equilibrium of two processes: formation of a solution and crystallization. If a saturated salt solution is used for calibration, attention must be paid to this equilibrium. Because solubility depends on temperature, a variation in the temperature of a saturated solution can disturb the dynamic equilibrium process in the solution. Time must be allowed for equilibrium when the temperature of a saturated solution is changed. This time period is usually significantly longer than the time required by the temperature of the solution to stabilize at a new value.

Non saturated solutions adapt faster to a change in temperature because they do not require a dynamic equilibrium between a crystal and a liquid. This is convenient for use in field calibrations where temperature is not precisely known ahead of time.

Most solutions release or absorb heat during their preparation. For that reason, solutions should be prepared in advance.

Are they all the same? Choosing the Right Humidity Instrument

November 2004

Selecting the right relative humidity instrument for a specific application can be confusing, largely because most instruments on the market have specifications that are almost identical. Consider, for example, the accuracy specification. Many instruments, of all cost and quality levels, specify accuracy of ± 2.0% RH or even better, regardless of the conditions to be measured. Is it possible that instruments that are so widely different both in design and cost are all equally good? Is an accuracy range of 1.0% to 2.0% RH commonplace? What about the long term stability of the humidity measurement? What role should it play into the decision process when selecting a RH instrument?

This article will first look at the principle of operation of capacitive humidity sensors, and then we will examine the source of errors in an RH measurement, and finally discuss the steps necessary to select the correct instrument.

Principle of Operation

The capacitive humidity sensor consists of a hygroscopic dielectric material placed between a pair of electrodes which forms a small capacitor. Most capacitive sensors use a plastic or polymer as the dielectric material, with a typical dielectric constant ranging from 2 to 15. When no moisture is present in the sensor, both this constant and the sensor geometry determine the value of capacitance.

At normal room temperature, the dielectric constant of water vapor has a value of about 80, a value much larger than the constant of the sensor dielectric material. Therefore, absorption of water vapor by the sensor results in an increase in sensor capacitance. At equilibrium conditions, the amount of moisture present in a hygroscopic material depends on both the ambient temperature and the ambient water vapor pressure. This is true also for the hygroscopic dielectric material used on the sensor.

By definition, relative humidity is also a function of both the ambient temperature and water vapor pressure. Therefore there is a relationship between relative humidity, the amount of moisture present in the sensor, and sensor capacitance. This relationship is the base of the operation of a capacitive humidity instrument.

In a capacitive instrument, as in practically every other type of instrument, humidity is measured by a chain process as opposed to being measured directly. Instrument performance is determined by all of the elements of the chain and not by the sensor alone. The sensor and associated electronics cannot be considered separately. Any factor that can disturb the chain process of measurement is bound to have an effect on the instrument's performance.

Classification of Errors

For the purpose of analysis, errors of measurement can be divided into two broad categories: Systematic and Random errors.

Systematic errors are predictable and repeatable, both in magnitude and sign. Errors resulting from a nonlinearity of the instrument or from temperature effects fall into this profile. Systematic errors are instrument specific.

Linearity Errors

The typical response of a relative humidity sensor (between 0 and 100% RH) is non-linear. Depending on the effectiveness of the correction made by the electronic circuits, the instrument may have a linearity error. Assuming that both the sensor and associated electronics have reproducible characteristics, the linearity error is a systematic error.

Generally, the values recommended by the instrument manufacturer for calibration were determined so as to minimize the linearity error. Calibrating at those values should produce an even plus and minus distribution of the linearity error. Careless selection of the calibration values can result in a different distribution of the linearity error and can be detrimental to instrument accuracy.

Temperature Errors

Temperature can have a major effect on several elements of the chain process of measurement described earlier. In the specific case of a capacitive humidity instrument, the following effects can produce a temperature error.

Sensor hygroscopic properties vary with temperature. A relative humidity instrument relies on the assumption that the relationship between the amount of moisture present in the sensor hygroscopic material and relative humidity is constant. However, in most hygroscopic materials, this relationship varies with temperature. In addition, the dielectric properties of the water molecule are affected by temperature. At 20°C, the dielectric of water has a value of about 80. This constant increases by more that 8% at 0°C and decreases by 30% at 100°C.

Sensor dielectrics properties also vary with temperature. The dielectric constant of most dielectric materials decreases as temperature increases. Fortunately, the effect of temperature on the dielectric properties of most plastics is usually more limited than in the case of water.

Any length of cable connecting the sensor to the electronic circuits has its own capacitance and resistance. The electronic circuits can not discriminate between the sensor and its connecting cable. Therefore, since the capacitance of the sensor and the cable can vary with temperature, the humidity values reported by the electronics must be compensated for the effects of temperature. Failure to do so can result in large measurement errors, sometimes as large and 15% to 20% RH.

While systematic errors are predictable and repeatable, random errors are not fully predictable because they are essentially dependant on factors external to the instrument. For example, errors resulting from sensor hysteresis, as well as those resulting from the calibration procedure are random errors. Usually, random errors are estimated on the basis of statistical data, experience, and judgment.

Hysteresis

Hysteresis is the maximum difference that can be measured between corresponding pairs of data, obtained by running an ascending and a descending sequence of humidity conditions. Hysteresis determines the repeatability of a humidity instrument.

For any given instrument, the value of hysteresis depends on a number of things: the total span of the humidity cycle used to measure hysteresis, exposure time of the sensor to each humidity condition, temperature during the measurements, criteria used to determine sensor equilibrium, and previous sensor history. Usually, sensor hysteresis increases as the sensor is exposed to high humidity and high temperature over longer periods of time.

Because of these points, it is not meaningful to state a sensor's hysteresis values without providing details on how the tests were performed. In actual measurement practice, conditions are extremely diverse and hysteresis may or may not reach its maximum value. Therefore, it is reasonable to consider hysteresis a random value that can be neither fully predicted nor compensated. When the accuracy of an instrument is specified, half the maximum value of hysteresis should be equally distributed as a positive and a negative error. However, instrument repeatability should not be specified at less than the full value of hysteresis.

Calibration Errors

Calibration consists of adjusting the instrument output to the values provided by two or more reference humidity conditions. The accuracy to which these conditions are known is critical. The reference instruments used to provide known humidity and temperature values for calibration have their own accuracy, repeatability, and hysteresis values which must be taken into consideration when specifying final instrument accuracy. In addition, no adjustment made during calibration can perfectly replicate the value seen by the reference instruments. These errors must be considered and treated as random errors in the calculation of instrument accuracy.

Long Term Stability

Another factor which is crucial, and in fact as important if not more so that instrument accuracy, is the instrument's ability to return the same values for RH for a given humidity condition over a long period of time. This value, usually termed repeatability, measures an instruments ability to maintain its calibration in spite of shifting characteristics of the sensor and its associated electronics over long periods of time. Generally one can split the problem of repeatability into two areas: the ability of the sensor to maintain its response to a given humidity condition at a given temperature and the stability of the electronics over time.

Long term stability plays a critical role in the frequency of calibration required for a humidity instrument. In addition, the stability of the instrument also significantly affects the value of the measurement data received from the instrument between calibration cycles. Both of these points help determine the overall cost of choosing an instrument.

Choosing a Humidity Instrument

Given all of the difficulties of measuring humidity and the confusing claims of the majority of suppliers of humidity instrumentation, how can a proper and accurate instrument be chosen for a particular application? Since specifications for instruments produce a large range of cost and quality for the same specifications, how can the user find the correct instrument?

The most important point to understand is there no real physical standard for relative humidity calibration. As a result, there has probably been more abuse in specifying humidity instruments than any other type of instrument. This abuse leads to specifications which are of limited value when comparing instruments from various manufacturers. Therefore the user finds that he or she must dig deeper into the specifications and claims of the instrument manufacturer. To achieve this goal, the end user must carefully examine the supplier's claims and support documentation in the following areas: sensor linearity, temperature constants, calibration errors, long term stability of sensor and electronics, and hysteresis.

Wet Bulb / Dry Bulb - Description and Limitations

Summary

Wet- and dry-bulb temperature measurement is a commonly used technique for controlling relative humidity in environmental chambers.

ASTM standard E 337-84 reviews in great detail the wet- and dry-bulb technique. According to this standard, the accuracy which can generally be expected in the case of a ventilated dry- and wet-bulb device is in the range of 2 to 5 %RH.

This kind of accuracy is acceptable in the case of environmental chambers where both temperature stability and uniformity are specified to within 1 degree C. This is so because an uncertainty of 1 degree C on temperature automatically results in an uncertainty of 5 to 6 %RH at high humidity. However, some chambers which are specified to within 0.3 - 0.5 degree C permit and require better humidity control.

Newer humidity measurement techniques such as the HYGROMER C-94 capacitive humidity sensor have greater accuracy than that of the wet- and dry-bulb technique. Of equal importance is the fact that the sensor offers superior control characteristics over a wide range of temperatures and humidity. Unlike other capacitive sensors, the C-94 sensor performs accurately even at high humidity and temperature. The HYGROMER C-80 sensor can survive conditions from -50 to +200 C and from 0 to 100 %RH.

Problem Areas in the Wet- and Dry-Bulb Technique

There is no question that the wet- and dry-bulb measurement technique has a sound theoretical basis. The problem is that this technique is simple only in appearance. And, it is so widely accepted that many users are not anymore critical or careful. This results in a number of problems which are reviewed in the following paragraphs.

Non-Observance of Basic Requirements

In practice, there is a tendency to disregard some of the following requirements of the wet- and dry-bulb technique:

- Water temperature: the theory of the wet- and dry-bulb technique assumes that the temperature of the water used for the wet-bulb is equal to the temperature of the environment to be measured.

- Psychrometer Coefficient: the psychrometer coefficient is used to establish the psychrometric chart that converts wet- and dry-bulb temperature readings into relative humidity. This coefficient has to be determined for each specific design of psychrometer and in particular for each design of the wet-bulb.

- Purity of Water: psychrometric charts are established under the assumption that pure water is being used for the wet-bulb.

- Barometric Pressure: psychrometric charts are usually valid at the "standard" barometric pressure and require a correction at other pressures.

- Matching of the Thermometers: the wet- and dry-bulb thermometers should not only be accurate, but they should also be matched so as to minimize the error on the temperature depression readings (or temperature difference).

Interferences During Measurements

In an environmental chamber, errors of measurement can result of a poor choice in the mounting location of the wet- and dry-bulb thermometers. This is the case when the thermometers are installed too closely to a source of moisture (water supply for the wet-bulb, steam injector, etc.). Errors may also occur when the thermometers are too close to the walls of the chamber. It is important to mount the thermometers at a location where conditions are fairly representative of the average conditions inside the chamber.

Poor Handling and Maintenance

Proper handling and frequent maintenance are major requirements of the wet- and dry-bulb technique. Costly service calls frequently result of the following:

- Dirty Wick: the wick should never be directly be touched with fingers. A new wick should be flooded with distilled water so as to wash away any contamination. In an environmental chamber, the wick is continuously ventilated and tends to get dirty after some time. From a maintenance standpoint, this is probably the most bothering aspect of the dry- and wet-bulb technique.

- Wick Not Properly Pulled: the wick should sufficiently cover the wet-bulb thermometer so as to minimize errors due to heat conduction along the stem of the thermometer. The wick must also be in close contact with the surface of the thermometer.

- Wick Not Really Wet: a wick which is too old or which has been left to dry out, may not supply enough water. A properly wetted wick should have a glazed appearance.

Typical Accuracy of the Wet- and Dry-Bulb Technique

Most of the problems mentioned above have a direct influence on the accuracy of the wet- and dry-bulb technique. Specifically, most errors are on the wet-bulb temperature and on the temperature depression measurement.

Considering only the uncertainties on temperature measurement and psychrometric coefficient, ASTM Standard #E 337-84 indicates that the range of errors for ventilated wet- and dry-bulb devices goes from 2 to 5 %RH:

An error of 2 %RH corresponds to an error of 0.1C on temperature depression and 0.2C on dry-bulb temperature. An error of 5 %RH corresponds to an error of 0.3C on temperature depression and 0.6C on dry-bulb temperature. The most important factor appears to be the accuracy of temperature depression measurement.

Taking into account the many other potential sources of error, it can be assumed that the effective accuracy of the wet- and dry-bulb devices installed in most environmental chambers is not better than 3 to 6 %RH. The error tends to be the largest at low humidity and at low temperatures. At these conditions, readings are usually too high.

Operational Limitations of the Wet- and Dry-Bulb Technique

In addition to limitations regarding accuracy, the wet- and dry-bulb technique has other limitations which may be important in the case of environmental chambers:

- No measurement below the freezing point.
- Adds water to the environment (a problem with chambers operating at low humidity).
- Sluggish response and therefore, poor control characteristics. The wet-bulb temperature reacts slowly to changes in humidity because of the mass of the wet-bulb thermometer and wick. Slow reaction to changes in temperature is due to the time required by the water supply to adapt.
- Requires a water supply and, therefore, can support the growth of micro-organisms.
- Cannot be easily calibrated and trouble-shot.

Technical Information
For
Rotronic Products

Technical Information for Rotronic Products

Water Activity Instruments: A Comparison of Two Measuring Techniques

June / July 2004

A point-by-point comparison shows that there is no real advantage of the chilled mirror Aw meters over the lower priced instruments that use a relative humidity sensor.

Water Activity Measuring Techniques

Most laboratories measure water activity either with an instrument that uses a relative humidity sensor or with an instrument that uses a chilled mirror.

Instruments based on a relative humidity sensor are typically less expensive than the chilled mirror instruments. This raises the question of whether the chilled mirror Aw meters have enough inherent advantages such as speed, accuracy and measuring range to offset the disadvantage of both a higher price and higher maintenance requirements.

Speed of Measurement

The measurement of water activity is an indirect measurement. All Aw instruments measure the amount of water vapor in the air surrounding the product sample. The time required for the water vapor in the product sample to equilibrate with the air in the chamber varies significantly with the composition of the product and temperature stability between the product sample and the air. Typically the full equilibrium time requires 30 minutes or longer. Using a variety of methods to speed the measurement most Aw instruments available on the market today provide a reading of Aw in approximately 5 minutes.

Temperature Stability

Temperature stability always matters during Aw measurements. A temperature imbalance or the lack of temperature stability between the product sample and the chamber air volume can change the partial pressure of water vapor generated by the product sample. From this point of view all types of sensors, chilled mirror or relative humidity, are equally affected by temperature instability. When temperature is not stable, measurements take longer and/or are inaccurate. Therefore the product sample should always be in equilibrium with the measurement chamber. Since the length of time required to reach temperature equilibrium depends on the product sample and the difference in initial temperature of the product sample, be sure the instrument provides the capability to report temperature instability.

Accuracy

With a chilled mirror instrument, water activity must be computed using both the value of dew point and the value of temperature. A relative humidity sensor measures the water vapor directly and then compensates for any temperature variation from 25°C. The accuracy of this computation or compensation depends on the error made on the measurement of any of these parameters.

In the food industry, many water activity measurements deal with products in the range of 0.800 to 1.000 Aw. At room temperature, a good relative humidity sensor can measure a condition of 0.950 Aw with an accuracy of ± 0.01 Aw or better. In terms of dew point, the equivalent accuracy is ± 0.175°C. The majority of reference chilled mirror instruments on the market today are specified with a dew point accuracy of ±0.15 °C to ±0.2°C. Therefore at high Aw levels, instruments based on a RH sensor are as accurate as even the best chilled mirror.

Depending both on the model and on the manufacturer, the vast majority of water activity instruments are specified with an accuracy of ±0.01 aw to ±0.02 aw (±1.0 %RH to ±2.0 %RH). As opposed to this, water activity instruments that use the combination of a chilled mirror (dew point) and infrared thermometer are commonly specified with an accuracy of ±0.003 aw (±0.3 %RH) in the range of 0.10 to 1.00 aw. At first sight, this appears to make the chilled mirror based water activity instruments much more accurate than the other kinds of instruments.

To understand how the accuracy of a chilled mirror instrument is determined it is important to remember that water activity (Equilibrium Relative Humidity) has to be computed from the value of dew point and temperature. During this process, errors made on both parameters combine to affect the ending accuracy. Therefore, it is important to consider the individual accuracies of temperature and dew point:

Generally, infrared thermometry is considered to be more limited in terms of accuracy than a precision Pt 100 RTD temperature sensor. Even over the narrow temperature range typical of water activity measurement, it is reasonable to consider that temperature measurement with an infrared thermometer is no better than ±0.1°C. And as stated above, top of the line reference grade chilled mirror instruments (dew point) are typically specified with an accuracy of ±0.15 °C to ±0.2 °C.

How do these errors in temperature and dew point combine to affect Aw accuracies?

Water activity measurements in the range of 0.80 to 1.00 aw, at a temperature close to 25 °C, are fairly common. For these common conditions, combining a ±0.1 °C accuracy on temperature with a ±0.15°C accuracy on dew point gives the following results:

a) Actual conditions: 0.800 aw (80.0 %RH), 25.0 °C and Td = 21.3 °C (dew point)

Using the error on dew point and temperature the error band of aw can be calculated with commonly available psychometric software. The calculation shows that the accuracy range on dew point alone results in an error of ±0.007 aw. When this is combined with the accuracy on temperature, the error on water activity becomes as large as ±0.012 aw

b) Actual conditions: 0.950 aw (95.0 %RH), 25.0 °C and Td = 24.1 °C (dew point)

The accuracy on dew point alone results in an error of ±0.009 aw. When this is combined with the accuracy on temperature, the error on water activity becomes as large as ±0.014 aw

Water activity is not always as high as 0.80 aw ...0.95 aw. For example, pharmaceutical applications frequently deal with values below 0.10 aw. When humidity is below 19%RH (0.19 aw) at a temperature of 25 °C, water can condense on a chilled mirror either in the form of liquid or in the form of ice.

At values below 0 °C dew point, the frost point (ice) is always higher than the dew point (liquid). The difference between frost and dew point increases as the humidity decreases. Good reference chilled mirror instruments are equipped with a microscope to determine which form of condensation is present on the mirror. For example, at a condition of 25 °C and 5.0 %RH, the frost point is -15.50 °C and the dew point is - 17.25 °C (a difference of 1.75 °C). At a condition of 5.0 %RH (0.050 aw) and 25 °C, confusing the dew point and the frost point would result in an error of 0.007aw to 0.008 aw. And these errors are additive to the errors caused by the temperature and dew point measurement.

As can be seen from the examples above, the actual accuracy on water activity using a chilled mirror instrument is at best ±0.015 aw. Essentially the same as those achieved using a RH sensor based system.

Range of Measurement

The ability of chilled mirror instrument to measurement low humidity values depends both on the power available to cool the mirror and on the evacuation of heat away from the mirror. Typical chilled mirror Aw instruments are limited tin these two areas and should not be used to measure products that are below 0.10 Aw. By contrast, a value of 0.01 Aw can be measured without problems with a relative humidity sensor.

Maintenance

Many products contain volatile additives and some products are in the form of a fine powder. Because the chilled mirror operates at condensation, there is the tendency to trap airborne contaminants on the mirror. Since deposits on the mirror clearly affect accuracy, frequent mirror cleaning is required. Good relative humidity sensors are unaffected by the vast majority of contaminants typically seen in food and pharmaceutical products. Due to this, calibration and maintenance requirements of an RH based Aw system is significantly lower than a chilled mirror system.

Summary

Which water activity system is right for you? The majority of instruments on the market today will provide equally accurate readings. When comparing RH sensor based systems the most important consideration is the long term stability and repeatability of the RH sensor. When comparing RH based systems with chilled mirror based systems there is no accuracy advantage. Therefore, base your decision on all the factors important to your use. Considerations such as instrument flexibility, ease of use, maintenance requirements, cost, and system software all play an important role.

Chemical Resistance of Rotronic Hygromer Humidity Sensors

General

Capacitive polymer humidity sensors react to the presence of certain chemicals within the surrounding gas.

The amount of the influence depends on a lot of parameters:

- Type of chemical
- Concentration
- Length of the influence
- Amount of humidity and temperature
- Presence of other chemicals

By that it is in principle impossible to make predictions about the deviation and the lifetime of the sensor. Normally it makes no sense to do specific tests in the laboratory, because they require too much work. It is most convenient to put test probes to the customer's disposal.

Uncritical chemicals

Following gases have no influence on the sensor and the humidity measurement:

Argon	Ar
Carbon dioxide	CO_2
Helium	He
Hydrogen	H_2
Neon	Ne
Nitrogen	N_2
Nitrous oxide (Laughing gas)	N_2O
Oxygen	O_2

Following gases have no or little influence on the sensor and the humidity measurement:

Butane	C_4H_{10}
Ethane	C_2H_6
Methane	CH_4
Natural gas	
Propane	C_3H_8

Critical Chemicals

In the given concentrations the following gases have no or little influence on the sensor and the humidity measurement. The shown data are only guide values. The resistance of the sensor depends strongly from the temperature and humidity conditions and the length of the pollutant influence.

Table: Allowed Fault Caused From Pollutants: $\pm$ 2 % RH

Pollutant	Formula	Allowed Concentration Continuous Operation	
		ppm	mg/m^3
Acetic acid	CH_3COOH	800	2000
Acetone	CH_3COOH_3	3300	8000
Ammonia	NH_3	5500	4000
2-Butanone (MEK)	$C_2H_5COCH_3$	3300	8000
Chlorine	Cl_2	0.7	2
Ethanol	C_2H_5OH	3500	6000
Ethyl acetate	CH_3COOC_2H	4000	15000
Ethylene glycol	$HOCH_2CH_2OH$	1200	3000
Ethylene oxide	C_2H_4O	3	
Formaldehyde	HCHO	2400	3000
Hydrochloric acid	HCI	300	500
Hydrogen sulfide	H_2S	350	500
Isopropanol	$(CH_3)_2CHOH$	4800	12000
Methanol	CH_3OH	3500	6000
Nitrogen oxides	NO_X	5	9
Ozone	O_3	0.5	1
Petrol			150000
Sulfur dioxide	SO_2	5	13
Toluene	$C_6H_5CH_3$	1300	5000
Xylene	$C_6H_5(CH_3)_2$	1300	5000

Application Examples

Humidity Measurement in Sterilization Chamber (Ethylene oxide)

Customer application: Sterilization of medical equipment

Sensor: C-94

Concentration Ethylene oxide: 15% by volume
Carbon dioxide 85% by volume

Pressure:	0.2 to 2.5 bar absolute
Temperature:	app. 40°C
Humidity:	app. 80 %rh

Application experience:

The sensors have a lifetime of approximately 3 months. The chamber is in continuous operation.

Humidity Measurement in An Ozone Chamber

Sensor:	C-94
Concentration Ozone:	app. 500 ppm
Temperature:	app. 23°C
Humidity:	app. 50 %rh

Application experience:

The sensors have a lifetime of approximately 1 month at 500 ppm ozone.

Special Application – Humidity Measurement in Oil

Humidity measurement direct in oil is possible in principle. But the lifetime of the sensors depends strongly from the used oil.

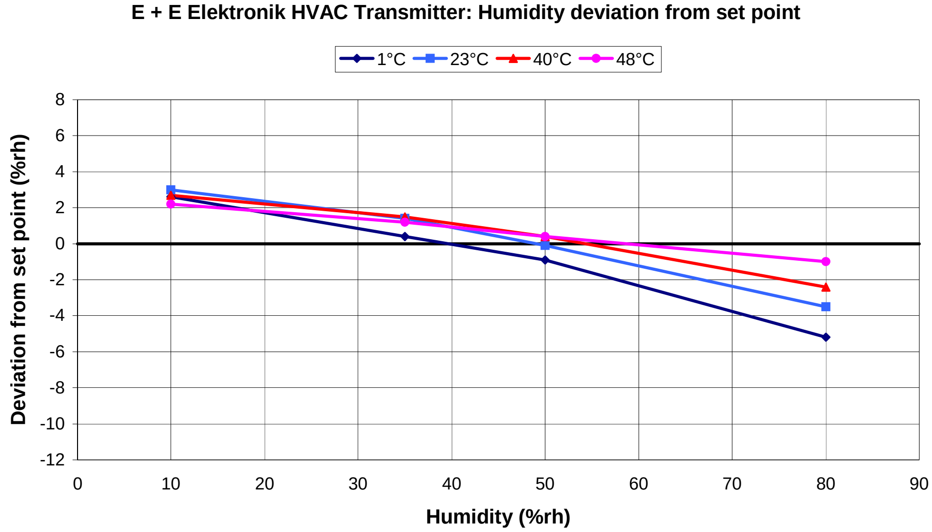
Measurements in oil are only possible with a special sensor and tests are inevitable. If you have an inquiry for such an application, please contact your Rotronic representative.

Competitor Comparison 2004

HVAC Transmitters - Wall Mount

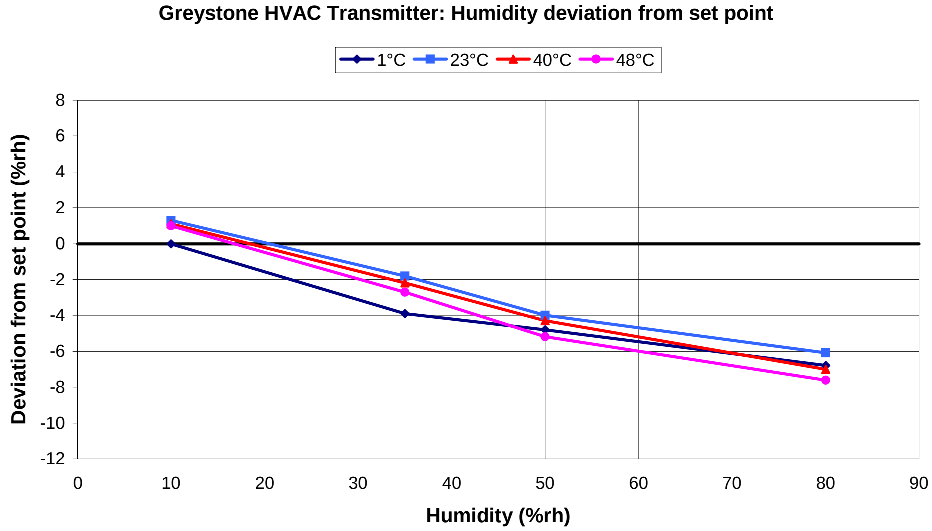
E + E Elektronik

Model	EE10-FT6-D04	Serial No. P19980_00020
Output	4..20 mA = 0...100 %rh, 0...+50°C, 2-wire	
Power	15...28 VDC	
Packing	Cardboard Box	



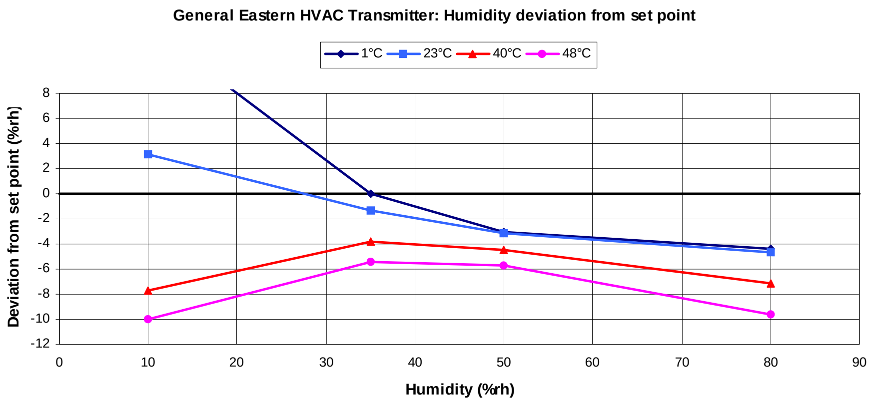
Greystone

Model	RH110A02C2A2	Serial No. N/A
Output	4...20 mA = 0...100 %rh, 0...50°C, 3-wire	
Power	24 V AC/DC	
Packing	Plastic Antistatic Bag	



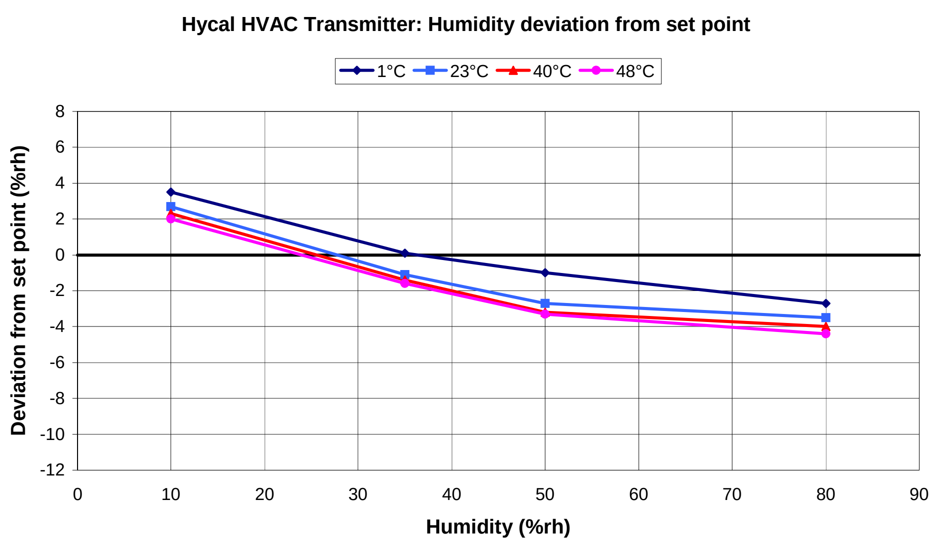
General Eastern

Model	MRH-2-S-T	Serial No. N/A
Output	4...20 mA = 0...100 %rh, -20...+140°F, 2-wire	
Power	12...36 VDC	
Packing	Cardboard Box	



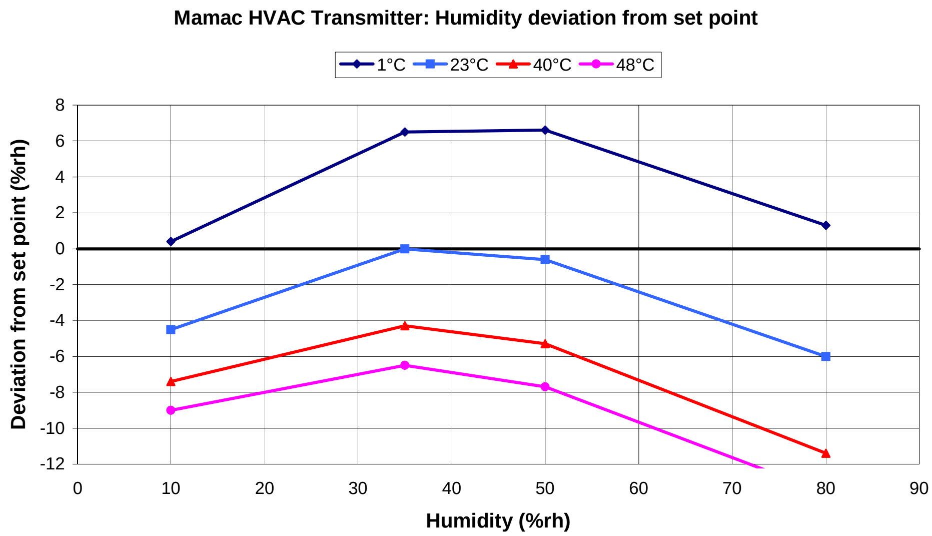
Hycal

Model	HHT-2SC-TTE	Serial No. 200305530
Output	4...20 mA = 0...100 %rh / 40...90°F, 2-wire	
Power	15...30 VDC	
Packing	Cardboard Box	



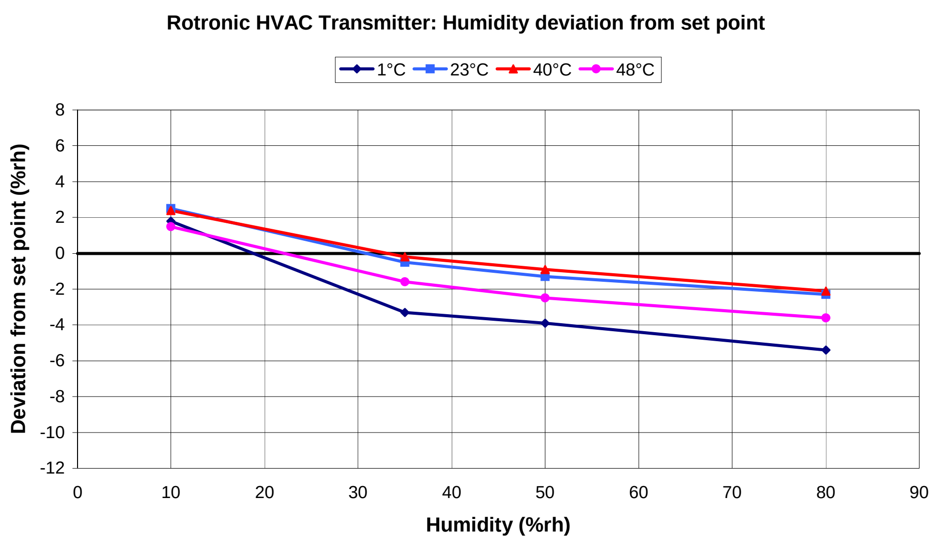
Mamac Systems

Model	HU-225-2-MA	Serial No. 63572
Output	4..20 mA = 0...100 %rh, no temperature, 2-wire	
Power	12...40 VDC	
Packing	Cardboard Box	



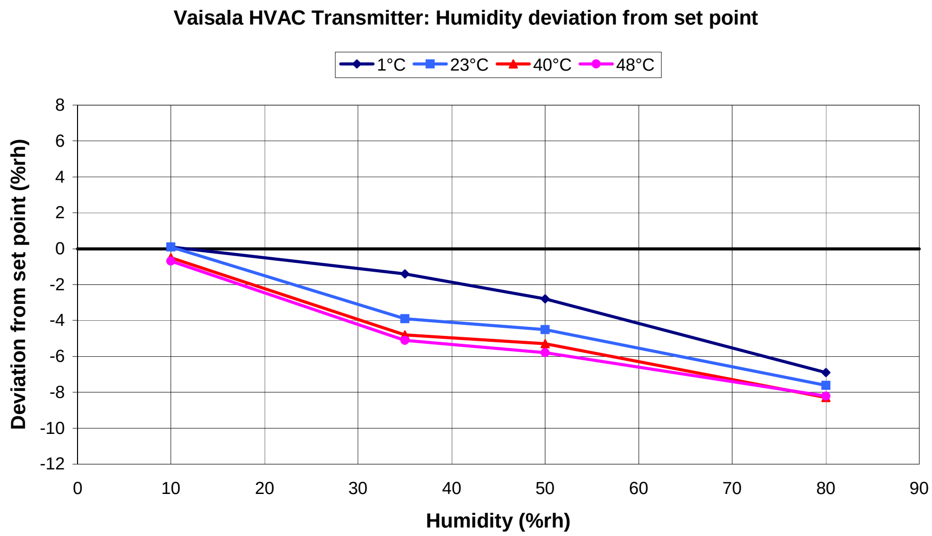
Rotronic

Model	L13SHT2	Serial No. 32621 010
Output	4...20 mA = 0...100 %rh / 0...50°C, 3-wire	
Power	10…35 VDC / 24 VDC	
Packing	Cardboard Box	



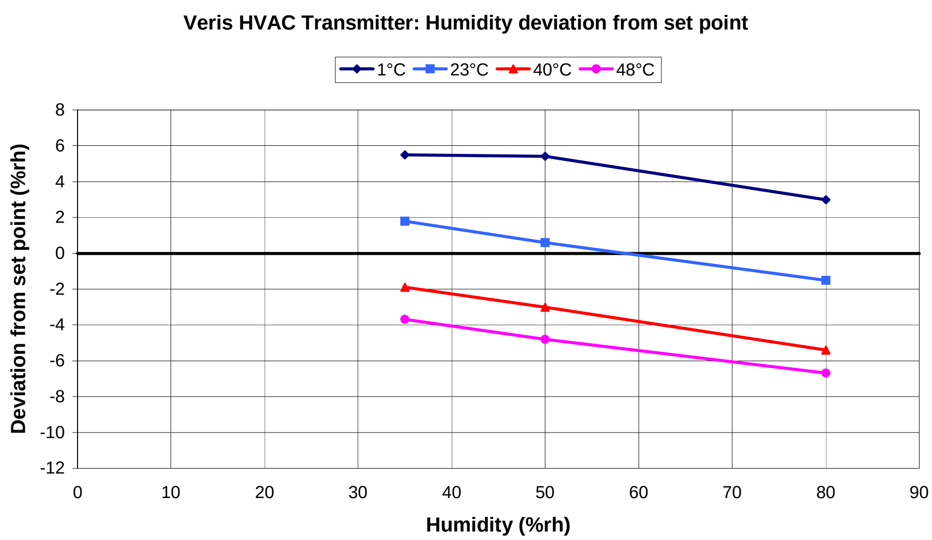
Vaisala

Model	HMW60Y	Serial No. Z0810046
Output	4..20 mA = 0...100 %rh, -5...+55°C, 2-wire	
Power	12...35 VDC	
Packing	Cardboard Box, PCB in plastic antistatic bag with silica gel bag	

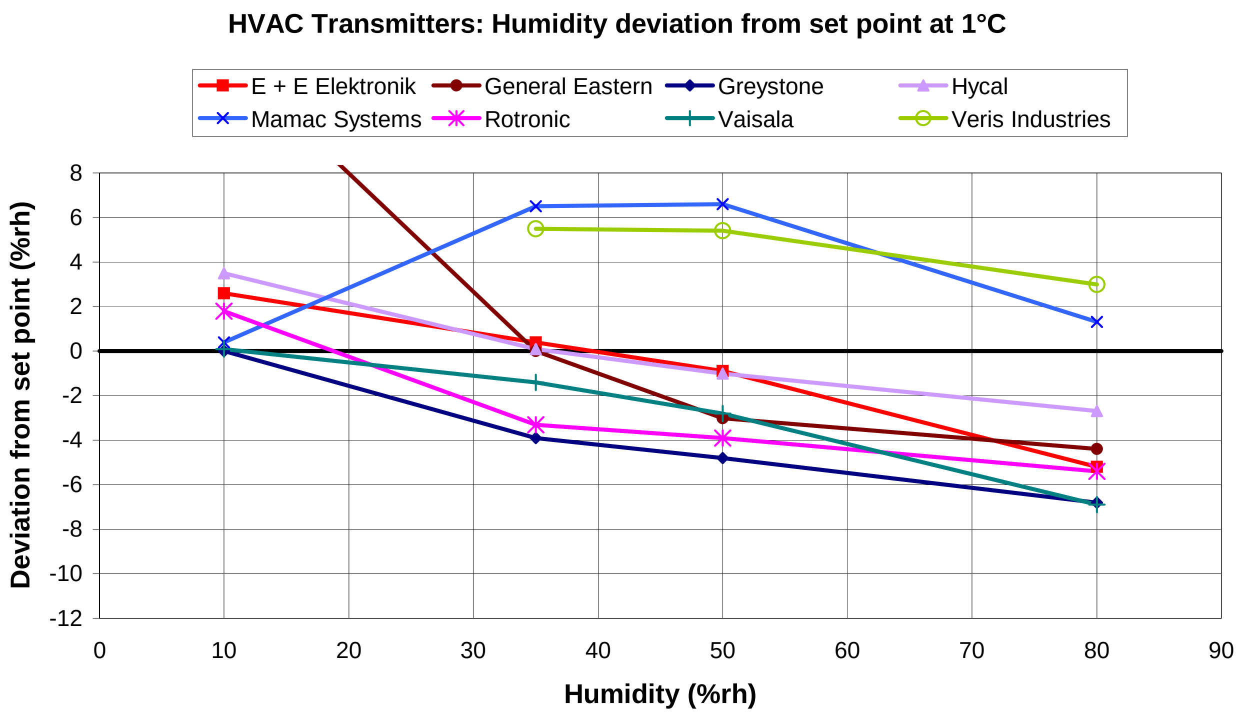


Veris Industries

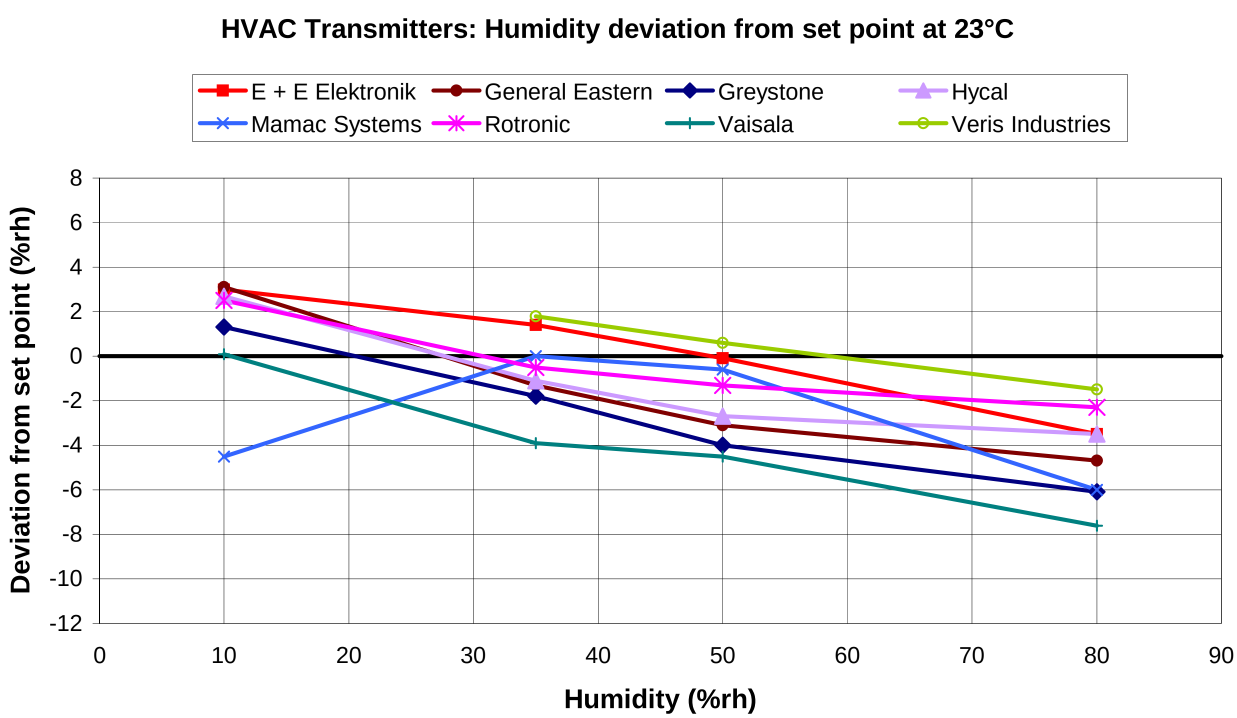
Model	HW Series	Serial No. N/A
Output	4...20 mA = 0...100 %rh / 32...122°F, 2-wire	
Power	12...24 VDC	
Packing	Blister	



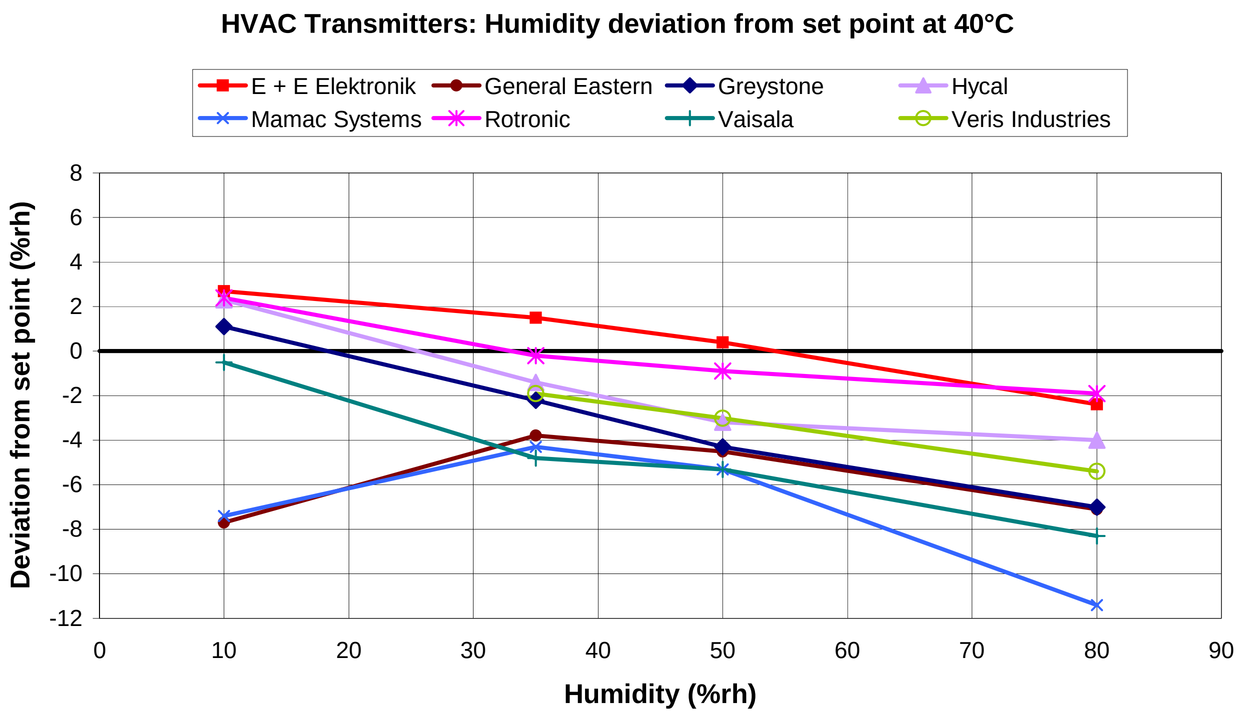
Humidity Deviation at 1°C



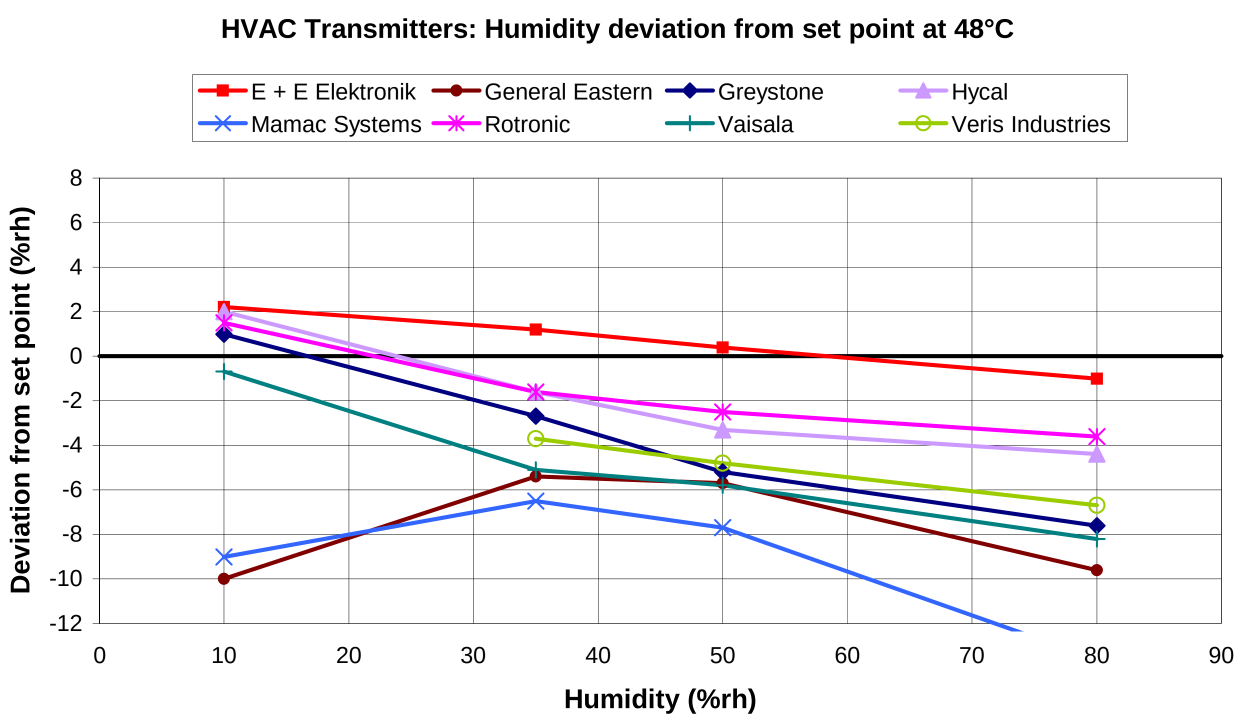
Humidity Deviation at 23°C



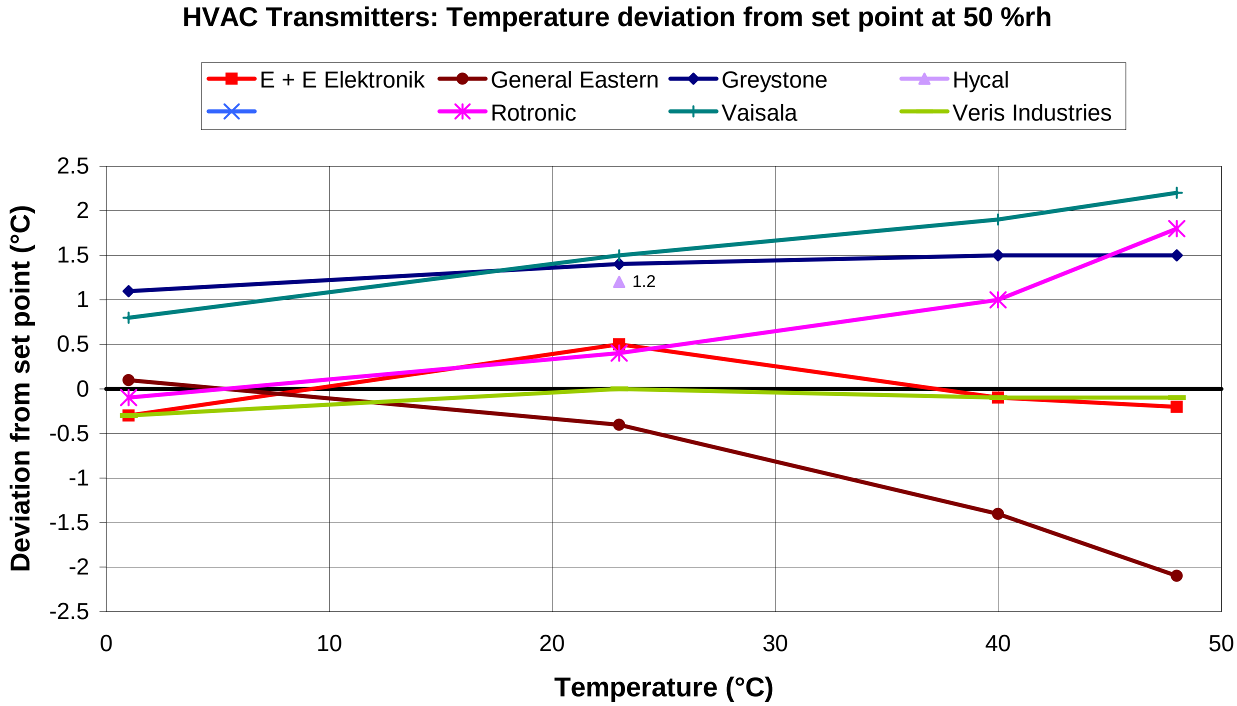
Humidity Deviation at 40°C



Humidity Deviation at 48°C



Temperature Deviation at 50 %rh

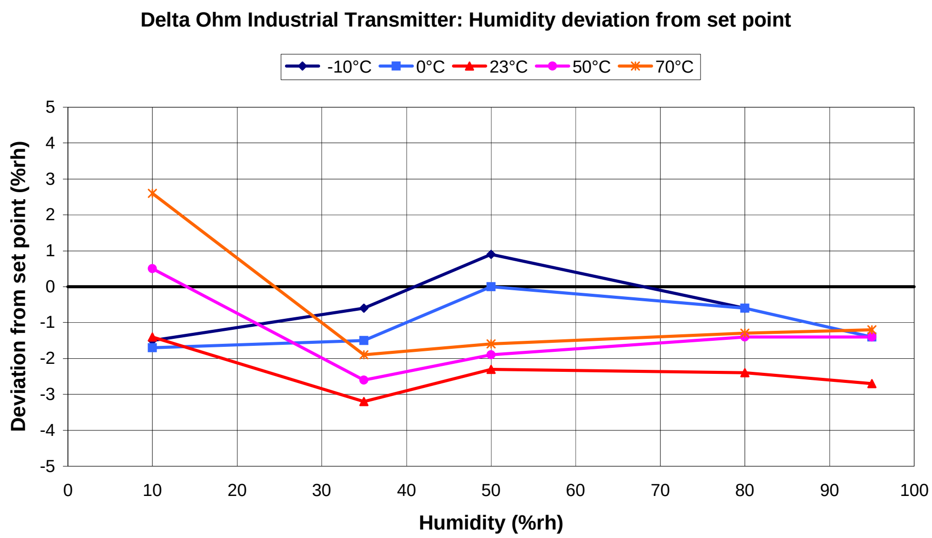


- Mamac: No temperature output
- Hycal: Temperature range only 40…90°F

Industrial Transmitters with Cable Probes

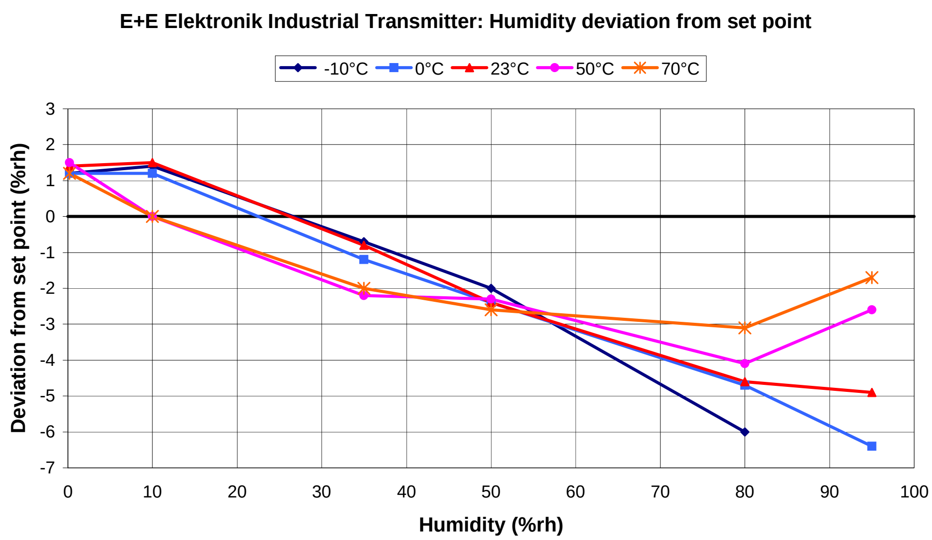
Delta Ohm

Model	HD2011TC/1 Serial No. Z0930004
Output	4..20 mA = 0...100 %rh, temperature range -30...+140°C, no temperature output
Power	24 VAC
Packing	Cardboard box



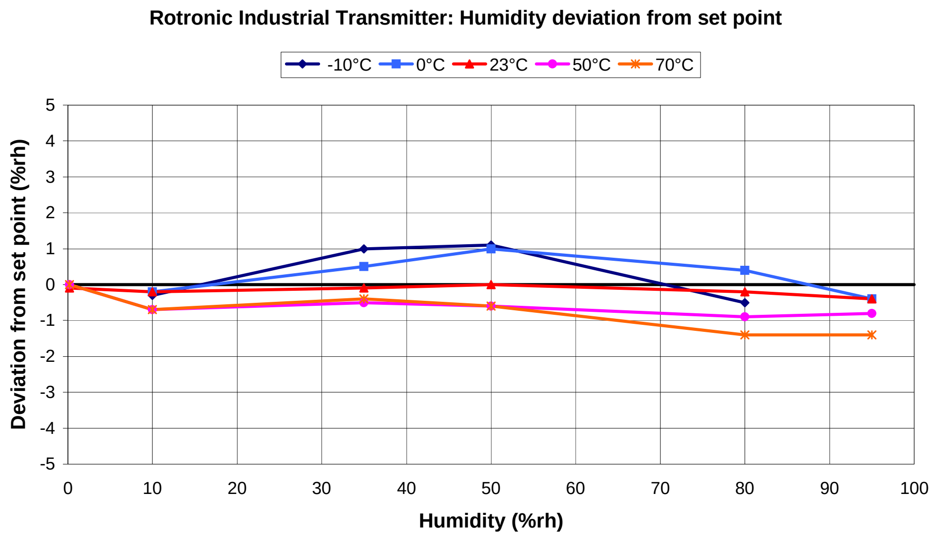
E + E Elektronik

Model	EE31-PFTD3025D05CA01AB6T5 Serial No. P20511
Output	4..20 mA = 0...100 %rh, -40...+180°C
Power	24 VDC
Packing	Cardboard box, calibration certificate, software



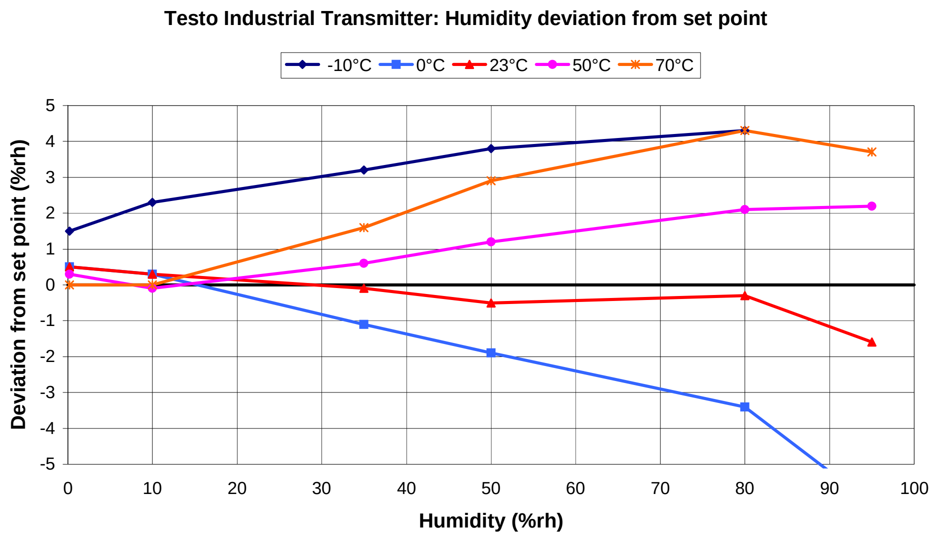
Rotronic

Model		Hygroclip IC-1		Serial No. 22112 003
Output		Digital 0…100 %rh, -50…+200°C
Power		9 VDC
Packing		N/A



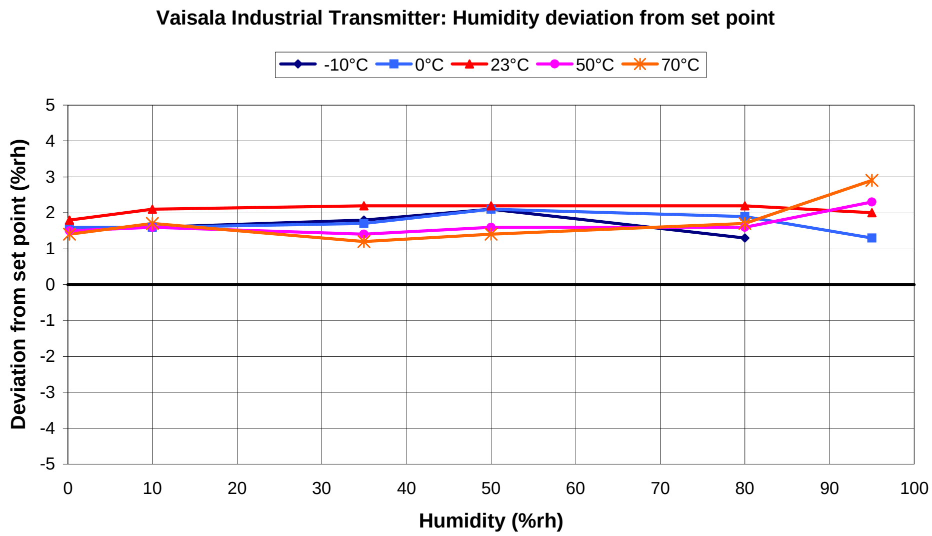
Testo

Model		Hygrotest 650 PHT - 20/180 Serial No. 35001583/403
Output		4..20 mA = 0...100 %rh, -20...+180°C
Power		24 VDC
Packing		Cardboard box, calibration certificate

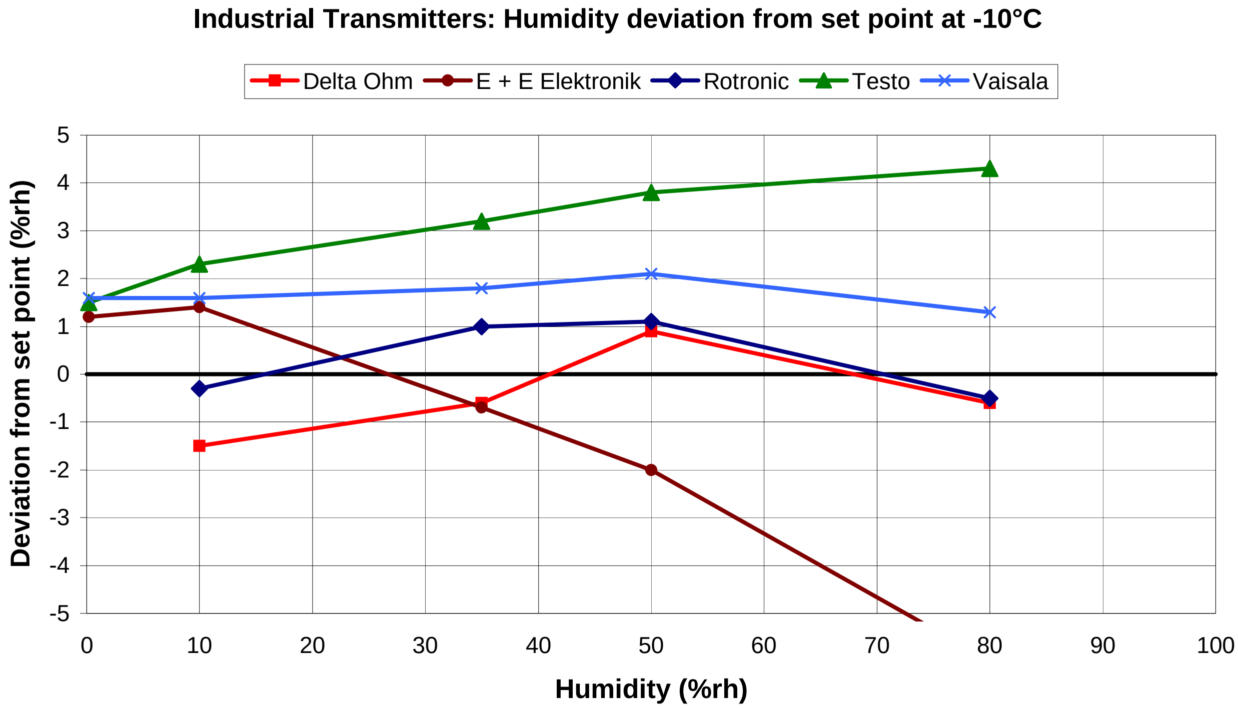


Vaisala

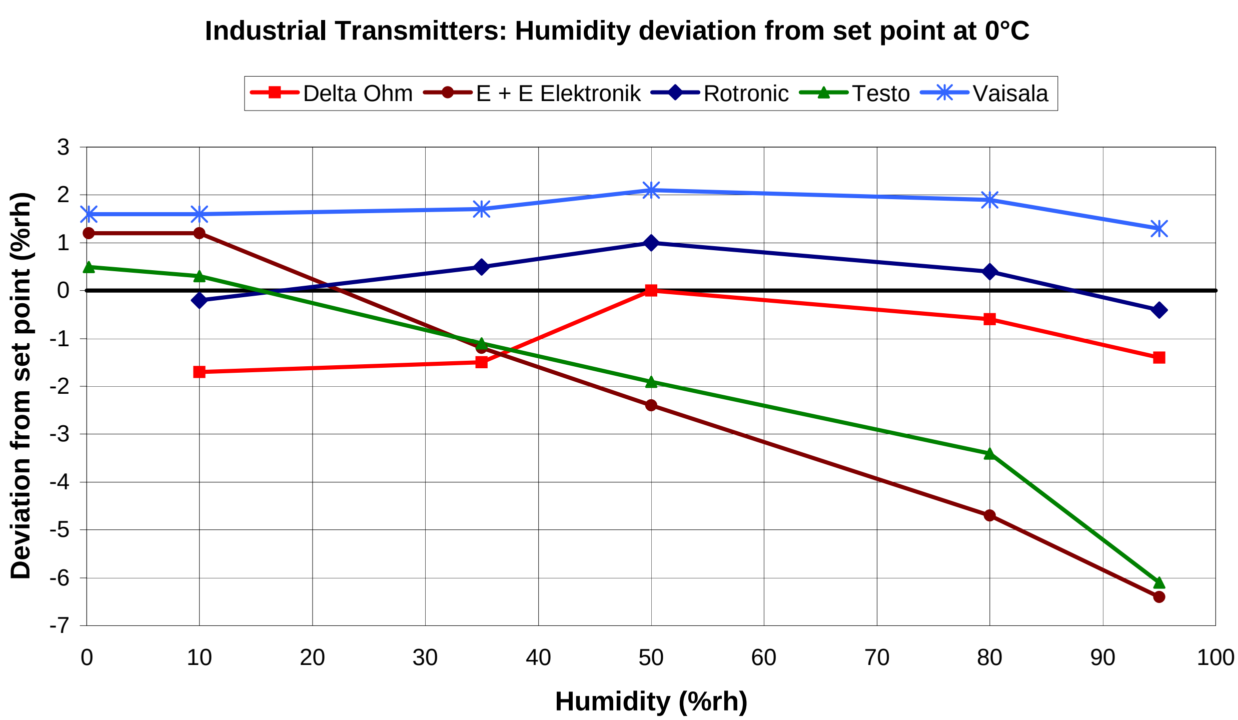
Model	HMP235 A2A0C2AA12A1A1C Serial No. Z0930004
Output	4..20 mA = 0...100 %rh, -20...+180°C
Power	24 VDC/AC
Packing	cardboard box, detailed calibration certificate



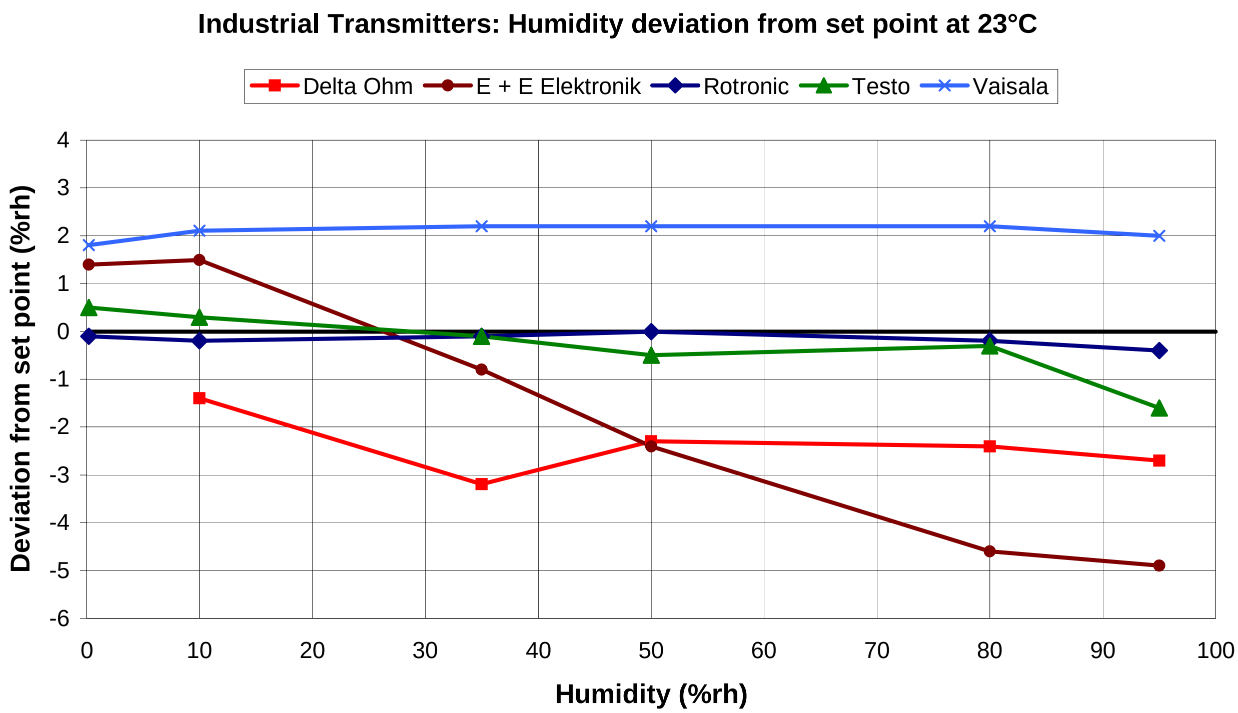
Humidity Deviation at -10°C



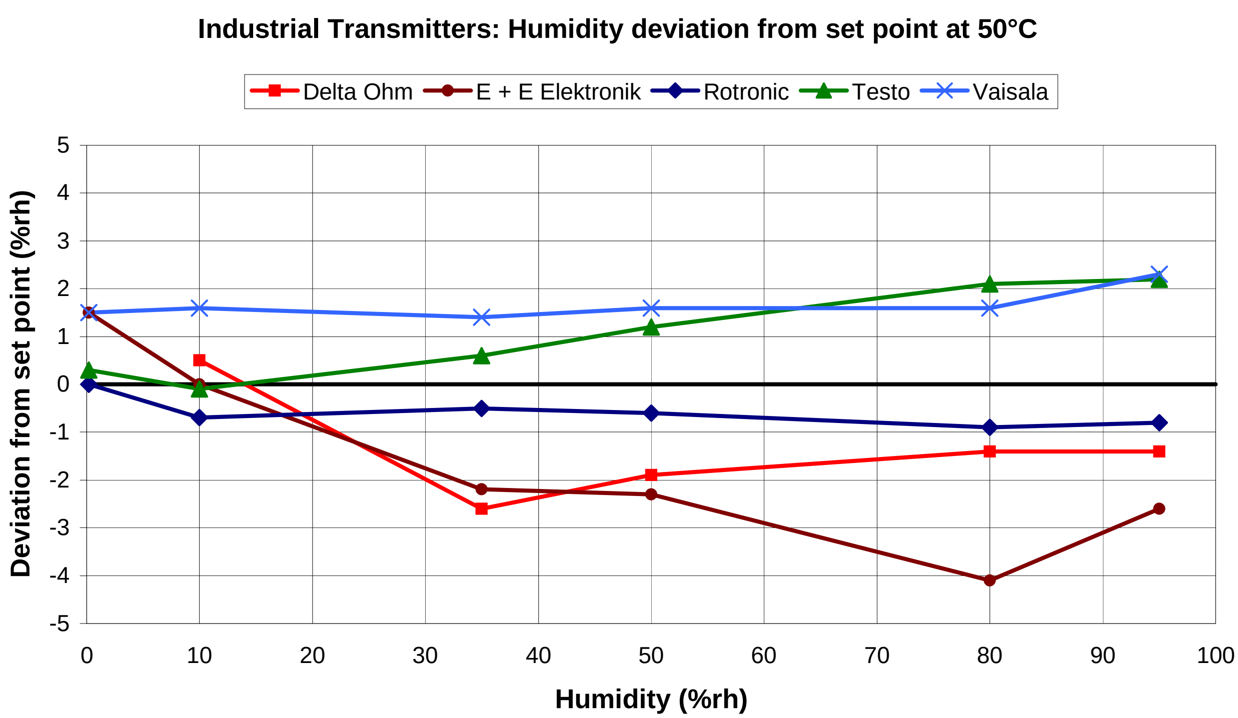
Humidity Deviation at 0°C



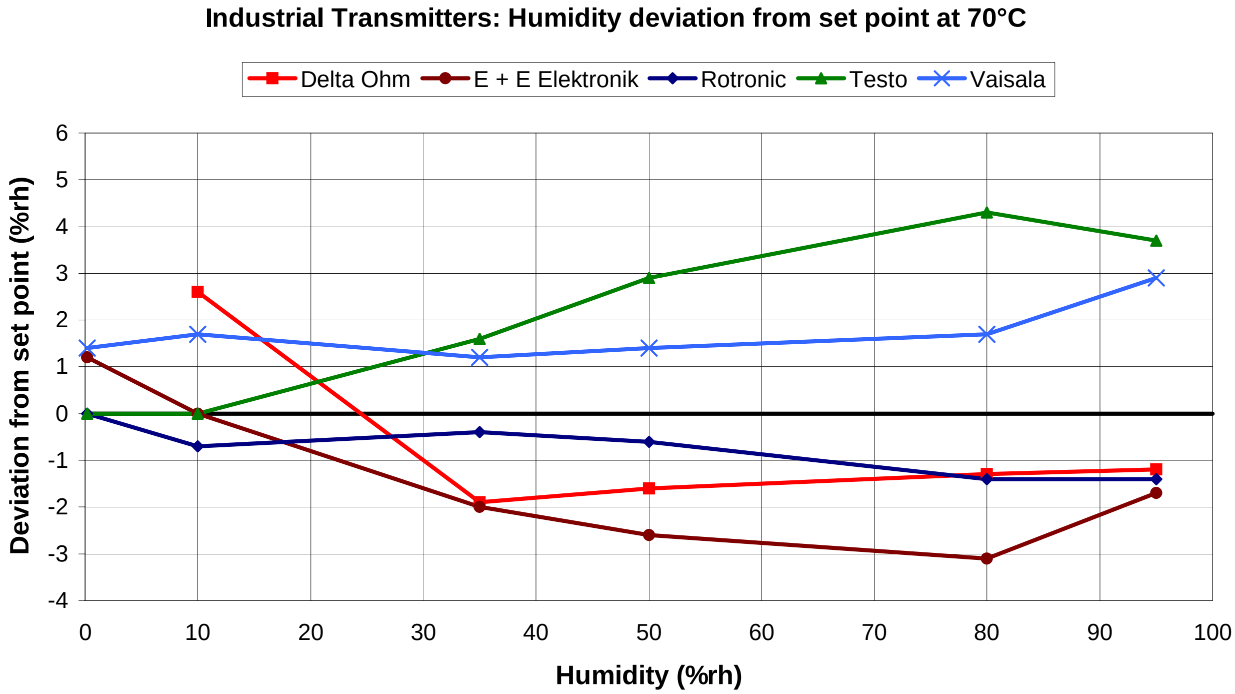
Humidity Deviation at 23°C



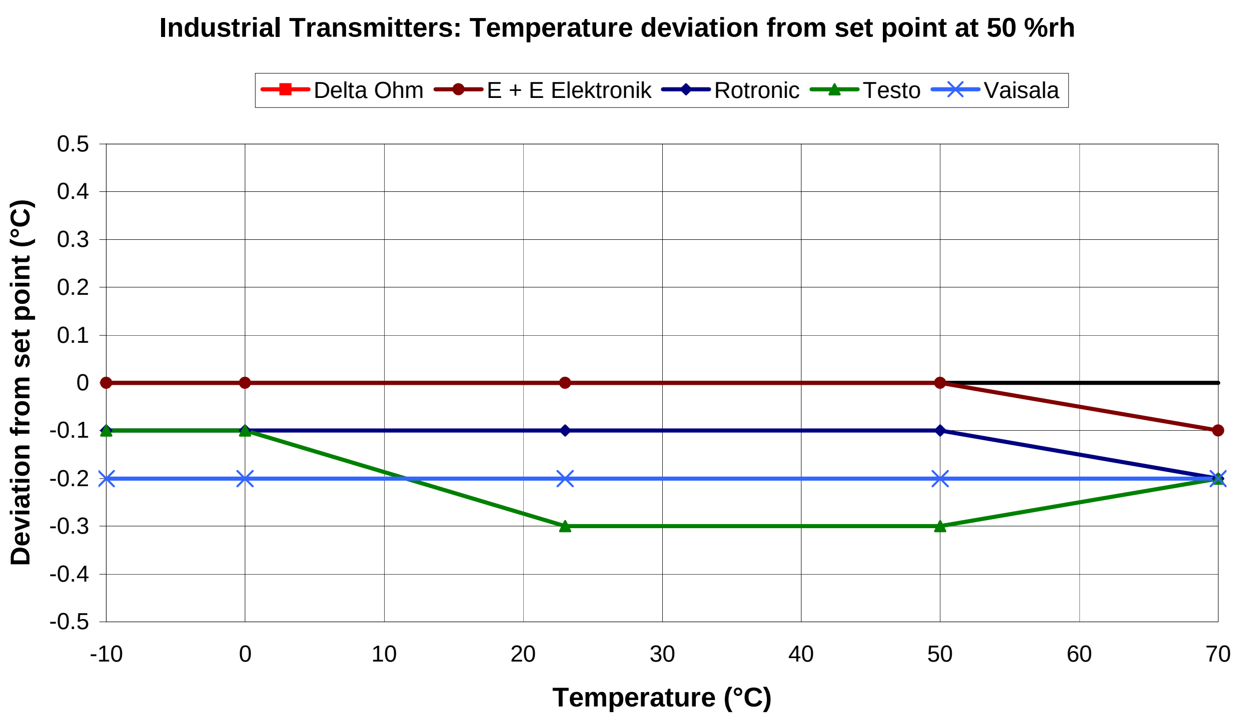
Humidity Deviation at 50°C



Humidity Deviation at 70°C

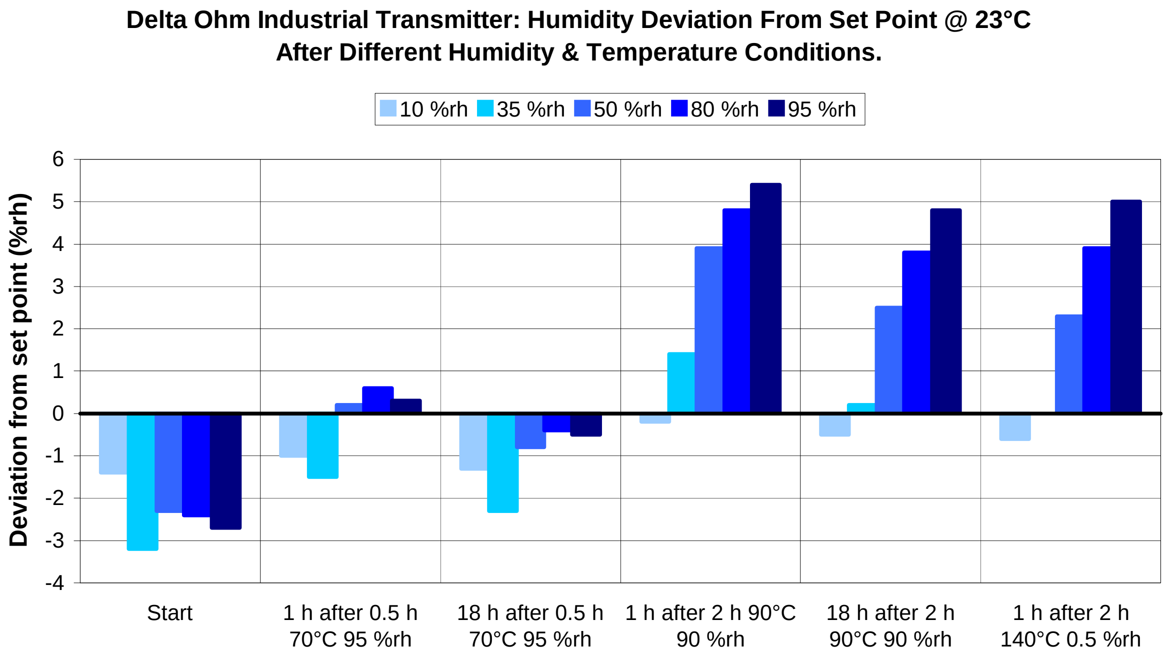


Temperature Deviation at 50 %rh

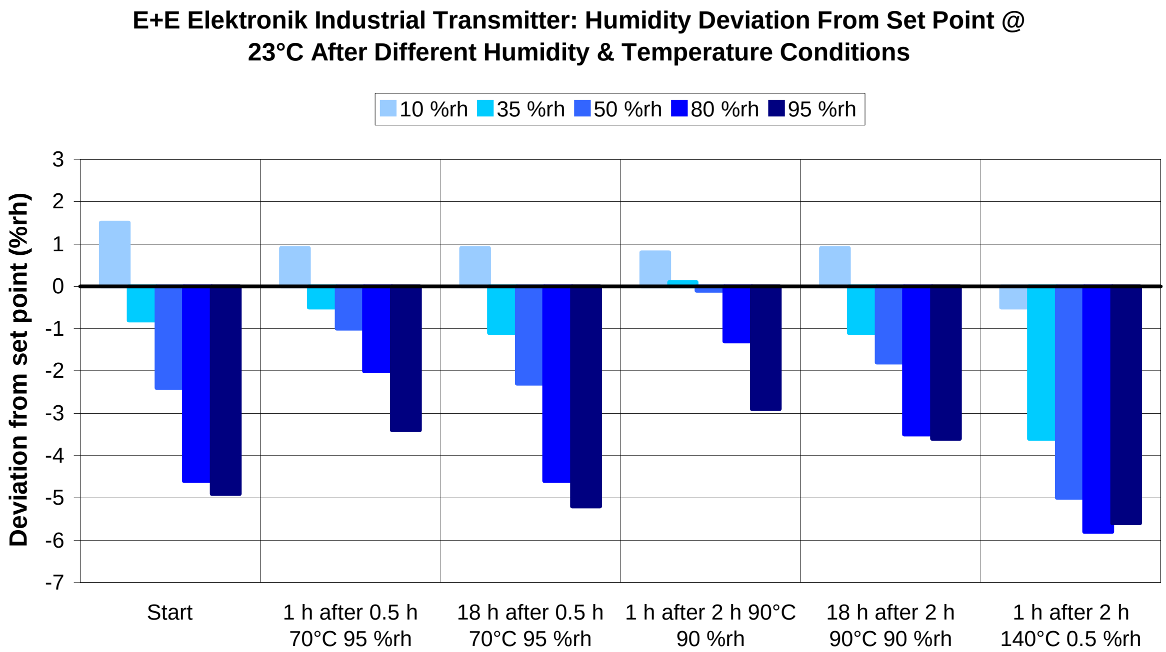


Humidity Deviation From Set Point at 23°C After Different Humidity and Temperature Conditions

Delta Ohm

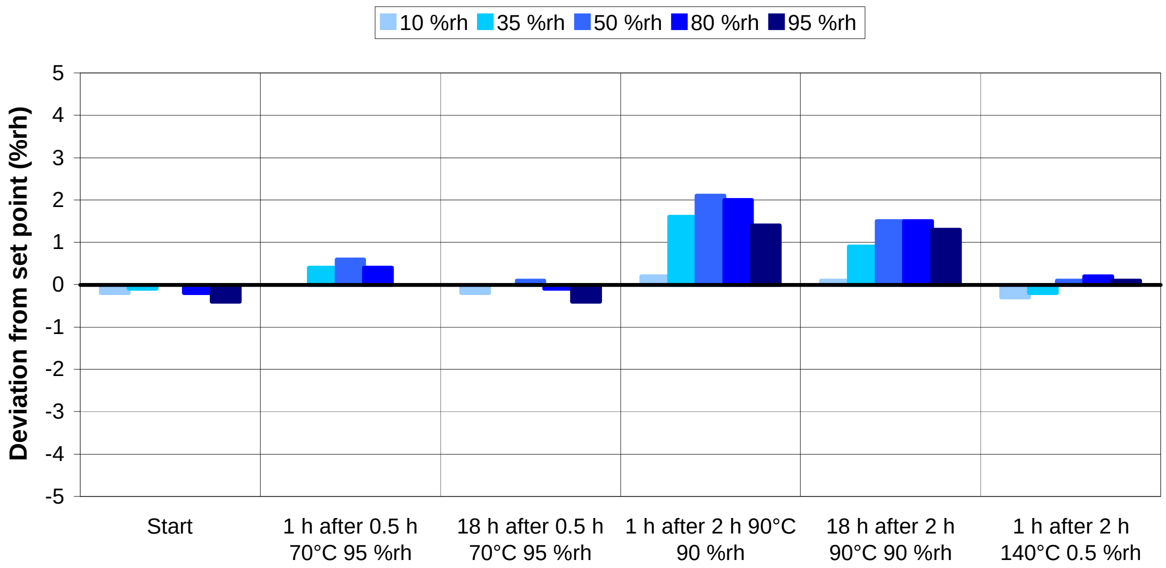


E + E Elektronik



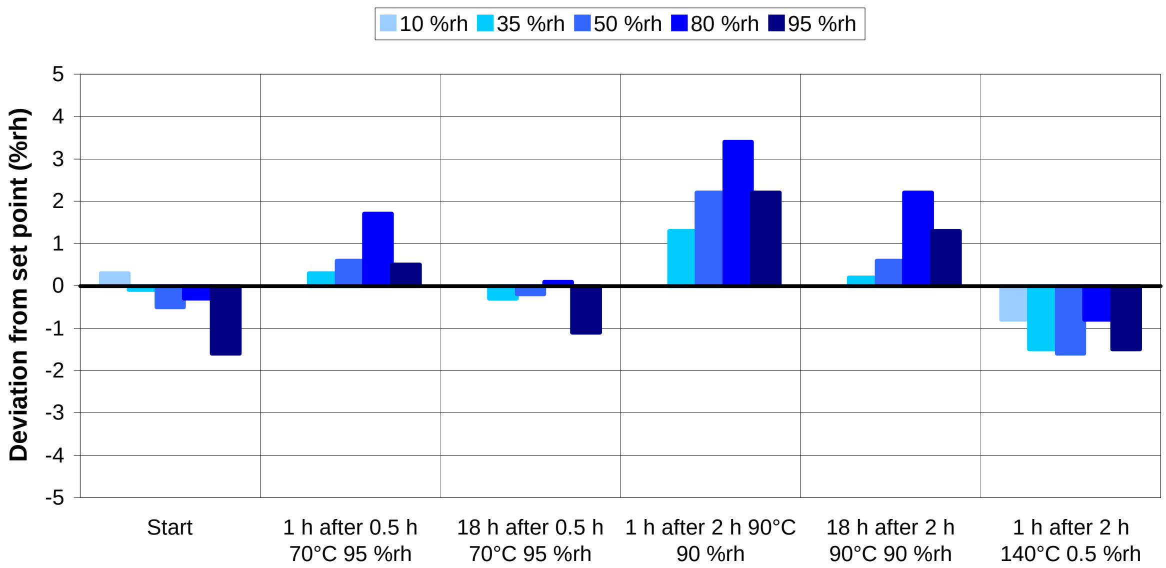
Rotronic

Rotronic Industrial Transmitter: Humidity Deviation From Set Point @ 23°C After Different Humidity & Temperature Conditions

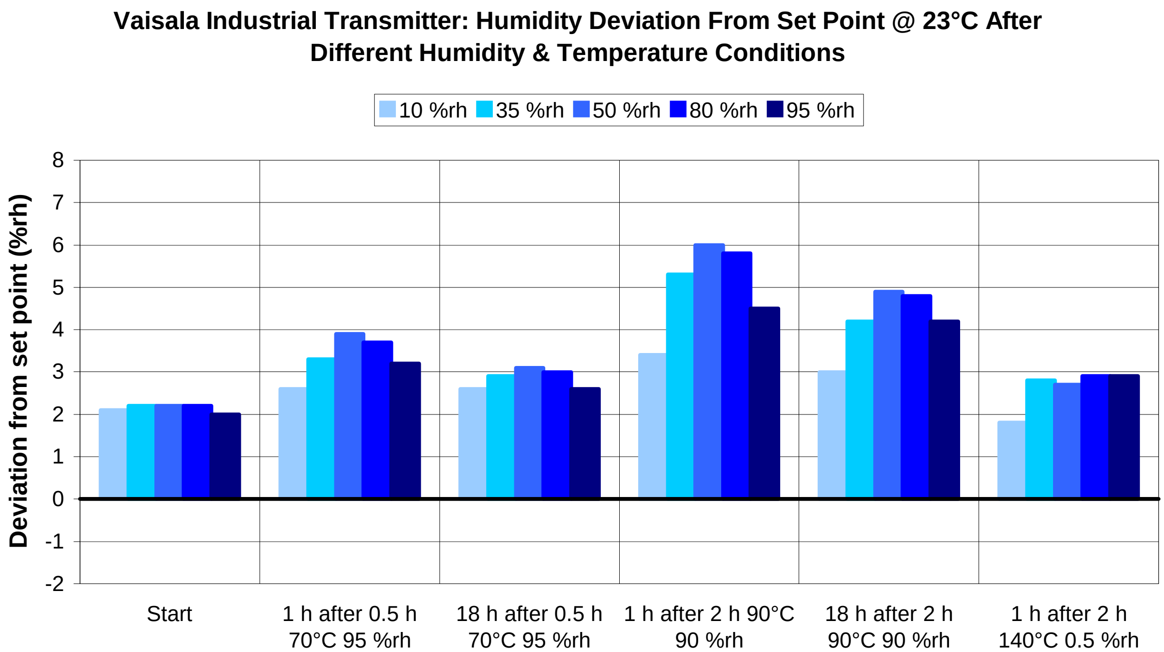


Testo

Testo Industrial Transmitter: Humidity Deviation From Set Point @ 23°C After Different Humidity & Temperature Conditions



Vaisala


Vaisala Industrial Transmitter: Humidity Deviation From Set Point @ 23°C After Different Humidity & Temperature Conditions
10 %rh
35 %rh
50 %rh
80 %rh
95 %rh
Deviation from set point (%rh)
8
7
6
5
4
3
2
1
0
-1
-2
Start
1 h after 0.5 h 70°C 95 %rh
18 h after 0.5 h 70°C 95 %rh
1 h after 2 h 90°C 90 %rh
18 h after 2 h 90°C 90 %rh
1 h after 2 h 140°C 0.5 %rh

HygroClip Performance Over A Range of %RH & Temperature Conditions

Reference - MBW – Dew Point		HygroClip S S/N 12880047		Error		HygroClip S S/N 12880073		Error	
Degree C	% RH	% RH	Degree C	%RH	C°	% RH	Degree C	%RH	C°
19.97	9.90	10.00	19.90	0.10	-0.07	10.00	19.90	0.10	-0.07
20.10	29.80	29.90	19.90	0.10	-0.20	29.80	20.00	0.00	-0.10
20.10	49.70	50.10	19.90	0.40	-0.20	50.00	20.00	0.30	-0.10
20.00	79.40	80.10	19.90	0.70	-0.10	80.00	20.00	0.60	0.00
20.00	94.30	94.60	20.00	0.30	0.00	94.50	20.00	0.20	0.00
9.98	9.90	9.80	9.80	-0.10	-0.18	9.80	9.80	-0.10	-0.18
9.99	29.60	29.50	9.80	-0.10	-0.19	29.30	9.90	-0.30	-0.09
10.03	49.20	49.60	9.90	0.40	-0.13	49.40	10.00	0.20	-0.03
10.02	78.60	79.10	9.90	0.50	-0.12	79.00	10.00	0.40	-0.02
10.03	93.20	93.10	9.90	-0.10	-0.13	93.00	10.00	-0.20	-0.03
-0.04	9.90	9.50	-0.20	-0.40	-0.16	9.50	0.00	-0.40	0.04
0.00	29.30	29.00	-0.10	-0.30	-0.10	28.80	0.00	-0.50	0.00
0.00	48.60	48.80	-0.20	0.20	-0.20	48.60	0.00	0.00	0.00
0.01	77.60	77.80	-0.10	0.20	-0.11	77.60	0.00	0.00	-0.01
0.01	92.40	91.50	-0.10	-0.90	-0.11	91.30	0.00	-1.10	-0.01
-10.02	9.80	9.10	-10.30	-0.70	-0.28	9.00	-10.10	-0.80	-0.08
-9.95	28.50	28.30	-10.20	-0.20	-0.25	27.90	-10.10	-0.60	-0.15
-9.97	47.40	47.40	-10.20	0.00	-0.23	47.20	-10.00	-0.20	-0.03
-9.98	75.80	75.40	-10.20	-0.40	-0.22	74.90	-10.00	-0.90	-0.02
29.94	10.00	10.10	30.00	0.10	0.06	10.20	30.00	0.20	0.06
29.96	30.00	30.20	30.00	0.20	0.04	30.20	30.00	0.20	0.04
29.97	50.10	50.70	30.00	0.60	0.03	50.60	30.00	0.50	0.03
30.08	80.00	80.60	30.10	0.60	0.02	80.60	30.10	0.60	0.02
30.04	94.80	95.20	30.10	0.40	0.06	95.00	30.20	0.20	0.16
39.89	10.00	10.20	39.90	0.20	0.01	10.40	40.00	0.40	0.11
39.94	30.10	30.60	40.00	0.50	0.06	30.60	40.00	0.50	0.06
39.98	50.30	50.90	40.00	0.60	0.02	50.80	40.00	0.50	0.02
40.01	80.40	81.00	40.10	0.60	0.09	80.90	40.10	0.50	0.09
40.07	95.40	95.70	40.20	0.30	0.13	95.50	40.20	0.10	0.13
49.88	10.10	10.50	50.00	0.40	0.12	10.70	50.00	0.60	0.12
49.91	30.30	31.10	50.10	0.80	0.19	31.20	50.00	0.90	0.09
49.95	50.50	51.30	50.10	0.80	0.15	51.40	50.00	0.90	0.05
50.03	80.80	81.40	50.20	0.60	0.17	81.40	50.20	0.60	0.17
50.11	95.80	96.30	50.30	0.50	0.19	96.20	50.30	0.40	0.19
69.81	10.20	10.90	70.00	0.70	0.19	11.10	69.90	0.90	0.09
69.93	30.60	32.20	70.10	1.60	0.17	32.30	70.00	1.70	0.07
70.01	51.00	52.10	70.20	1.10	0.19	52.20	70.10	1.20	0.09
70.17	81.30	82.10	70.50	0.80	0.33	82.00	70.30	0.70	0.13
70.38	96.30	97.30	70.70	1.00	0.32	97.10	70.50	0.80	0.12

Reference - MBW – Dew Point		HygroClip S S/N 13696012		Error		HygroClip S S/N 13696056		Error	
Degree C	% RH	% RH	Degree C	%RH	C°	% RH	Degree C	%RH	C°
20.06	10.00	9.90	20.10	-0.10	0.04	9.90	20.10	-0.10	0.04
20.08	30.00	30.10	20.10	0.10	0.02	30.10	20.10	0.10	0.02
20.09	50.00	50.30	20.10	0.30	0.01	50.40	20.10	0.40	0.01
20.11	79.90	80.40	20.10	0.50	-0.01	80.10	20.10	0.20	-0.01
20.14	94.70	95.00	20.20	0.30	0.06	95.00	20.20	0.30	0.06
10.17	10.00	9.90	10.10	-0.10	-0.07	10.00	10.10	0.00	-0.07
10.21	30.00	30.00	10.20	0.00	-0.01	30.00	10.20	0.00	-0.01
10.21	50.00	50.20	10.20	0.20	-0.01	50.40	10.20	0.40	-0.01
10.22	80.00	80.10	10.20	0.10	-0.02	80.30	10.20	0.30	-0.02
10.24	94.90	94.50	10.20	-0.40	-0.04	94.70	10.20	-0.20	-0.04
0.29	10.10	9.70	0.20	-0.40	-0.09	9.80	0.20	-0.30	-0.09
0.30	30.00	29.70	0.20	-0.30	-0.10	29.90	0.20	-0.10	-0.10
0.31	50.00	50.00	0.20	0.00	-0.11	50.30	0.20	0.30	-0.11
0.32	80.00	79.50	0.30	-0.50	-0.02	80.00	0.30	0.00	-0.02
0.33	95.00	93.70	0.20	-1.30	-0.13	94.20	0.20	-0.80	-0.13
-9.60	10.30	9.40	-9.70	-0.90	-0.10	9.50	-9.70	-0.80	-0.10
-9.57	30.20	29.80	-9.70	-0.40	-0.13	30.00	-9.70	-0.20	-0.13
-9.57	50.10	50.00	-9.70	-0.10	-0.13	50.30	-9.70	0.20	-0.13
-9.57	80.00	78.90	-9.60	-1.10	-0.03	79.50	-9.70	-0.50	-0.13
29.82	10.00	9.70	29.90	-0.30	0.08	9.70	29.90	-0.30	0.08
29.88	30.00	30.00	30.00	0.00	0.12	29.90	30.00	-0.10	0.12
29.91	50.00	50.20	30.00	0.20	0.09	50.00	30.00	0.00	0.09
29.96	80.00	80.40	30.10	0.40	0.14	80.20	30.10	0.20	0.14
30.00	94.80	95.20	30.10	0.40	0.10	95.00	30.10	0.20	0.10
39.70	10.00	9.60	39.90	-0.40	0.20	9.50	39.80	-0.50	0.10
39.76	30.00	29.90	40.00	-0.10	0.24	29.80	39.90	-0.20	0.14
39.79	50.00	50.00	40.00	0.00	0.21	49.80	39.90	-0.20	0.11
39.85	79.80	80.10	40.10	0.30	0.25	79.80	40.00	0.00	0.15
39.91	94.70	95.10	40.10	0.40	0.19	94.80	40.10	0.10	0.19
49.57	10.00	9.40	49.80	-0.60	0.23	9.30	49.70	-0.70	0.13
49.63	29.90	29.80	49.80	-0.10	0.17	29.60	49.80	-0.30	0.17
49.68	49.90	50.00	49.90	0.10	0.22	49.60	49.80	-0.30	0.12
49.76	79.80	80.00	50.00	0.20	0.24	79.50	50.00	-0.30	0.24
49.82	94.80	95.30	50.10	0.50	0.28	95.00	50.00	0.20	0.18
69.42	10.00	9.00	68.80	-1.00	-0.62	8.90	69.60	-1.10	0.18
69.47	29.90	29.90	69.80	0.00	0.33	29.50	69.60	-0.40	0.13
69.56	49.90	50.00	69.90	0.10	0.34	49.40	69.70	-0.50	0.14
69.71	79.80	79.90	70.10	0.10	0.39	79.10	69.90	-0.70	0.19
69.85	94.60	95.20	70.20	0.60	0.35	94.60	70.10	0.00	0.25

Evaluation of Competitive Humidity Sensors

This section compares the performance of seven (7) commercial humidity sensor systems as they were available from key manufacturers in 1997.

Testing procedures were defined by ZURICHSEE – LABOR, an independent research laboratory near Zurich, Switzerland. Results may differ from those published by the manufacturers.

For questions regarding the study please contact Zürichsee-Labor Engineering Office for Safety and Environment Bahnhofstrasse 5, CH-8820 Wädenswil – Switzerland. Phone / Fax: +41-1-780 83 30.

Manufacturer / Color Code	Model of Sensor
ROTRONIC	Hygromer C-94
ROTRONIC	Hygromer DMS-100
VAISALA	Humicap 180
VAISALA	Humicap H
TESTO	600
E+E	HC-1000
PANAMETRIC S	Mini Cap II

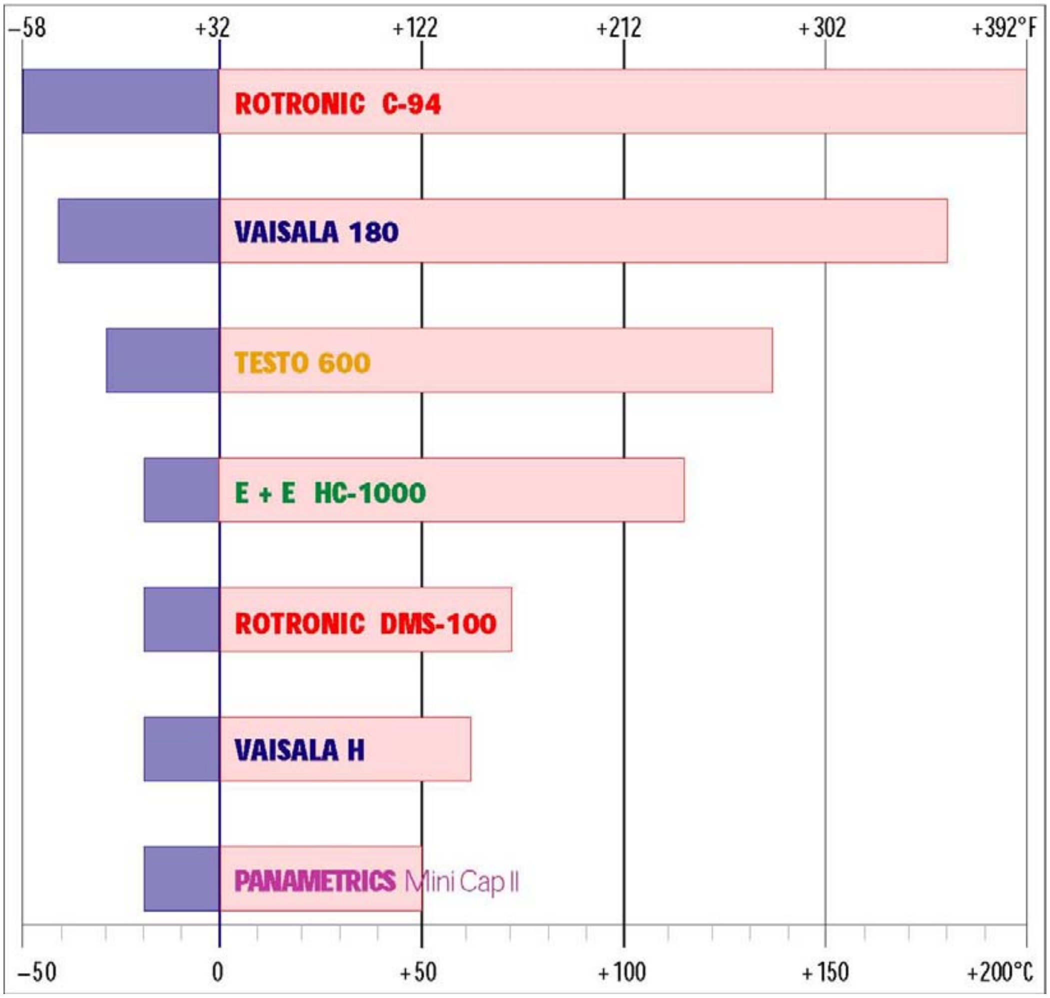
Temperature Limits – Response Time – Reset Rate – Long Term Accuracy – Dew Point Stability

April 1998
Zürichsee – Labor
Engineering Office for Safety and Environment Bahnhofstrasse 5
CH-8820 Wädenswil – Switzerland
Phone / Fax: +41-1-780 83 30

Temperature Limits

Most humidity sensors have a defined temperature range where their function is guaranteed within limits of accuracy. If a humidity sensor is used beyond its temperature limits, it may display erroneous values or get permanently damaged.

In the following comparison, the sensor ROTRONIC Hygromer C-94 had the widest temperature limits:

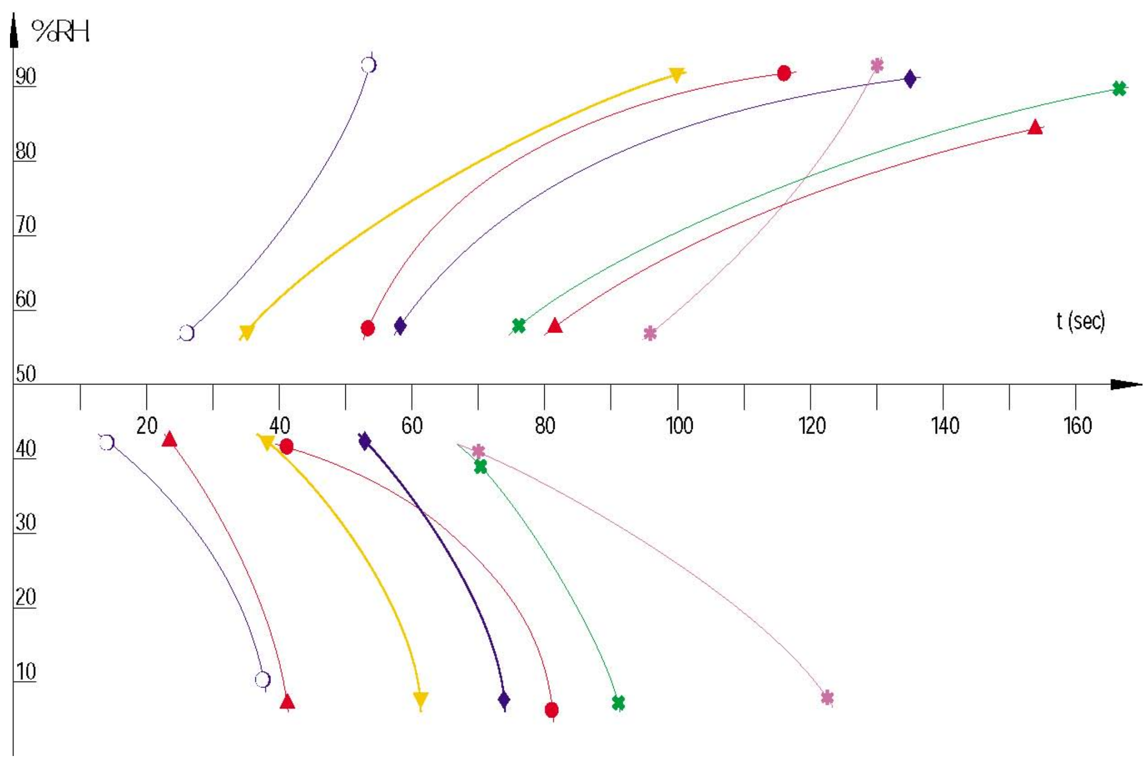


The temperature limits of a sensor device may determine the application areas of the entire gauge consisting of sensor, probe and instrument. A wide temperature range is advantageous also for accuracy within that range. All sensors tested had the highest accuracy in the center of their temperature range. They were considerably less accurate at their lower and upper temperature limits.

Response Time

The response time of a humidity sensor is the time it takes to respond to a changing set of humidity conditions, deviating from a standard 50% R.H.

In the comparison below, the sensor VAISALA Humicap 180 took 40 seconds to go from 50% R.H. to 70% R.H. The response time for 90% R.H. was 55 seconds. Thus, VAISALA Humicap 180 was the fastest of all evaluated sensors both, on the wet and on the dry side.



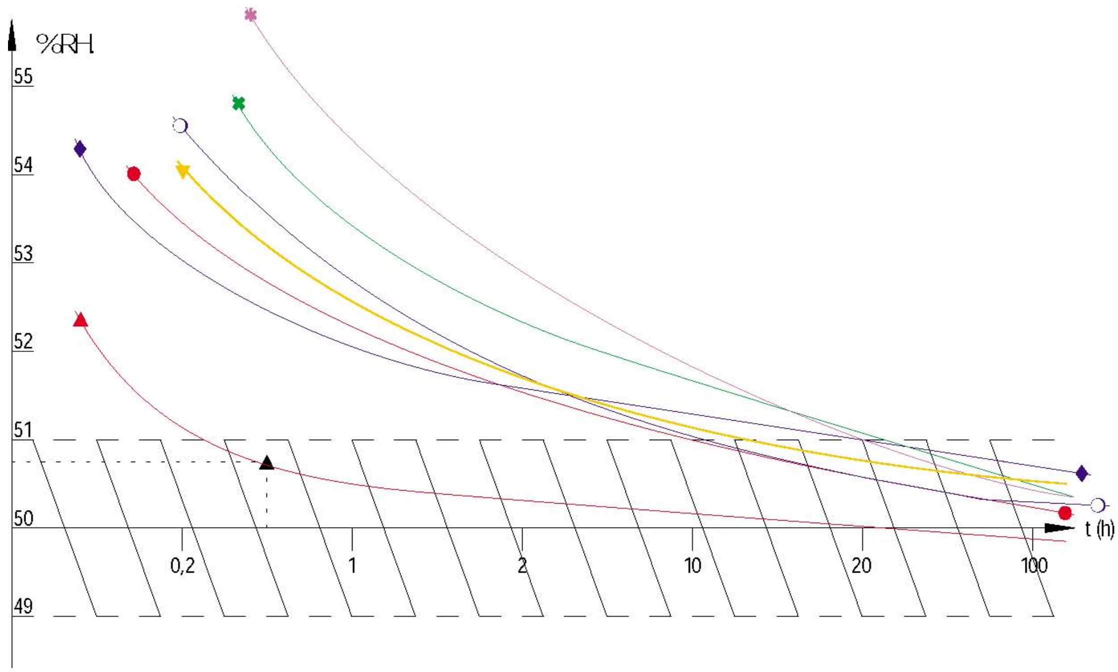
● ROTRONIC Hygromer C.94	O VAISALA Humicap 180
▲ ROTRONIC Hygrolyt DMS .100	♦ VAISALA Humicap H
* PANAMETRICS Mini Cap ll	x E+E HC-1000
▼TESTO 600	

A short response time is advantageous in process control, where it leads to higher process linearity. In applications where large numbers of humidity measurements must be run in sequence, short response times help save time and cost.

Reset Rate

The reset rate determines the time (in hours) a humidity sensor takes to reset to 50% R.H. after it was exposed to 95% R.H. for 24 hours. A drawback of most polymeric hygroscopic materials used as dielectrics in capacitive humidity sensors is, that they retain humidity longer than desirable. Thus, polymeric sensors hesitate to reset, and consequently indicate higher values than they should, for quite long periods of time.

In the comparison below, the sensor ROTRONIC Hygrolyt DMS-100 had the shortest reset rate. It took ½ hours to reset to 50...51% R.H., a factor 20 faster than any other sensor system.



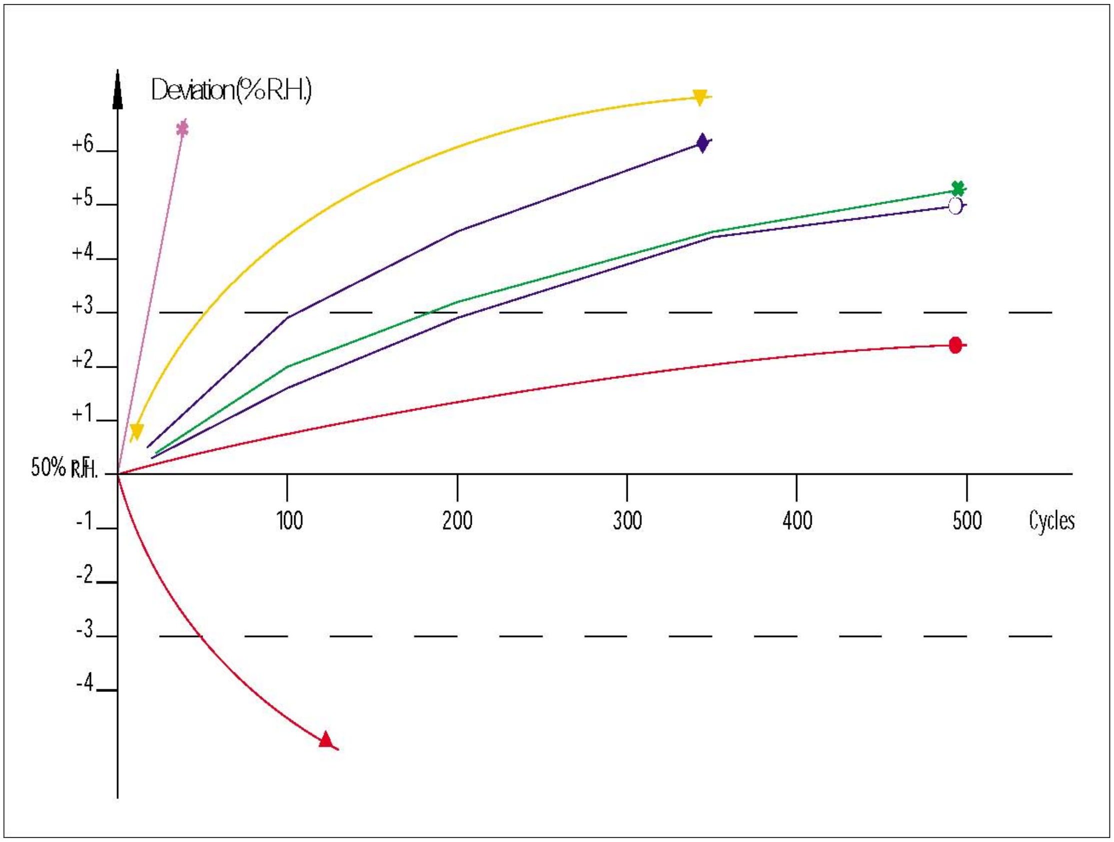
● ROTRONIC Hygromer C.94	O VAISALA Humicap 180
▲ ROTRONIC Hygrolyt DMS .100	♦ VAISALA Humicap H
* PANAMETRICS Mini Cap ll	x E+E HC-1000
▼TESTO 600	

A quick reset rate is a determining factor in rough climate, when humidity is high and monitoring of fog, dew point, etc. must be done in short intervals. In non-meteo applications such as food processing or water adsorption, the reset rate is a key factor for process control.

Long Term Accuracy

Long term accuracy differs, of course, from application to application. Under mild conditions, all sensors may have adequate long term accuracy. This test studied the performance under adverse conditions, running 3-hour cycles alternating as follows: “high” cycle = +90 °C and 90% R.H. · “low” cycle = –20 °C and 5% R.H. After every 100 cycles, the deviation from the set point at 50% R.H. was recorded.

In the comparison below, the sensor ROTRONIC Hygromer C-94 had the highest long term accuracy, i.e. deviated least from the set point at any given number of cycles:



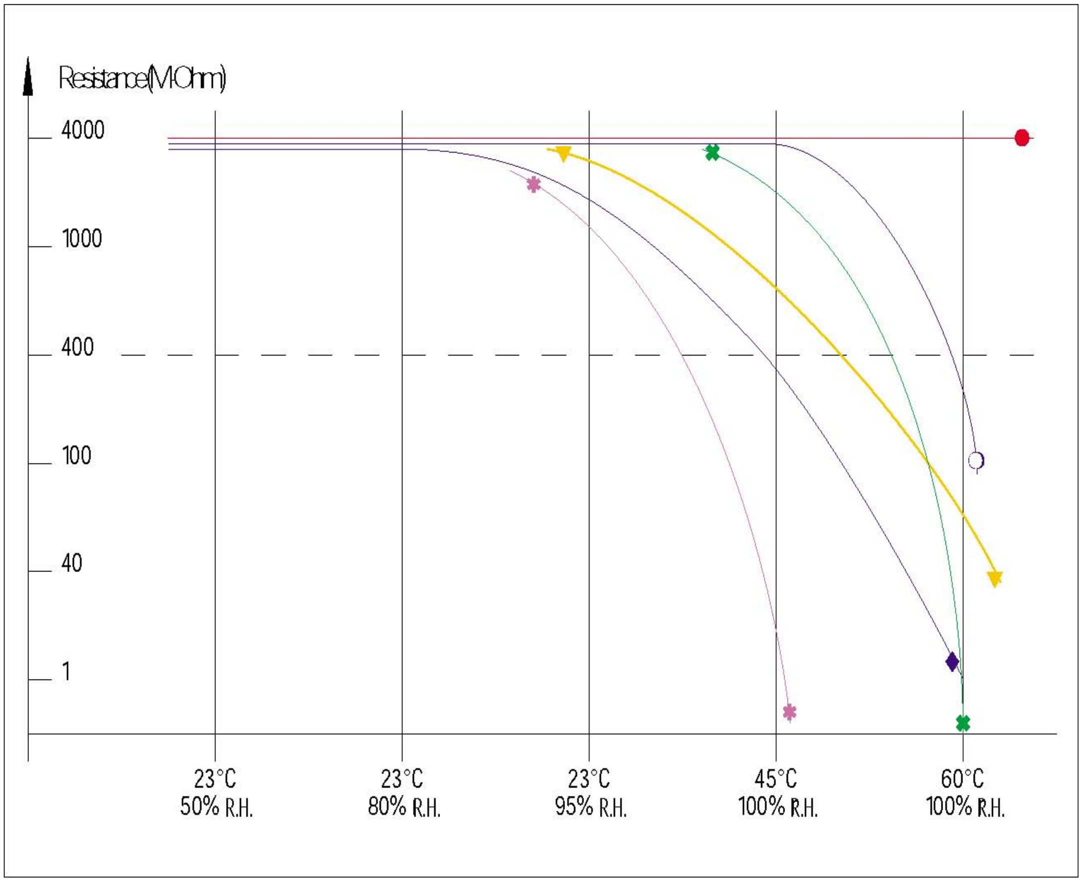
● ROTRONIC Hygromer C.94	O VAISALA Humicap 180
▲ ROTRONIC Hygrolyt DMS .100	♦ VAISALA Humicap H
* PANAMETRICS Mini Cap II	x E+E HC-1000
▼TESTO 600	

Long term accuracy determines the reliability of humidity measurements under adverse conditions. It is equally important if equipment is in remote locations, is difficult to access or if service intervals are long.

Dew Point Stability

All tested sensors disliked dew point conditions. Because of formation of water droplets on the sensor surface, unreliable readings resulted. Sensors with small surface areas were particularly sensitive.

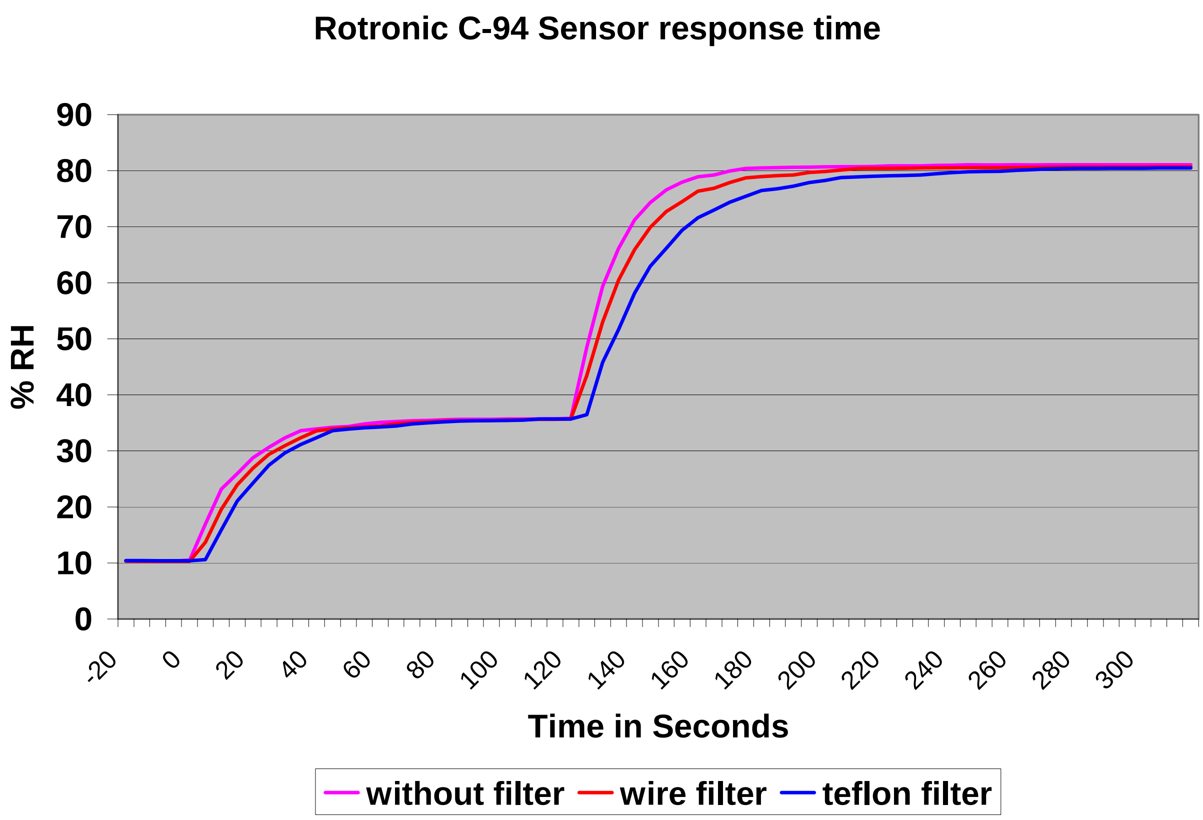
In the comparison below, the sensor ROTRONIC C-94 had, relatively, the best dew point stability:



● ROTRONIC Hygromer C.94	O VAISALA Humicap 180
▲ ROTRONIC Hygrolyt DMS .100	♦ VAISALA Humicap H
⋆ PANAMETRICS Mini Cap II	x E+E HC-1000
▼TESTO 600	

The rate at which a humidity sensor recovers from dew conditions is an equally important consideration in dew point stability. Some sensor electronics may get permanently damaged (shorted) from dewing. The sensor devices per se do recover, however, at rates similar to those shown under 'reset rate'.

Rotronic C-94 Response Time



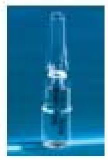
Response Time in Seconds (1 meter per second airflow)

Change	C-94 Without Filter	C-94 With Wire Mesh Filter	C-94 With Teflon Filter
t 63	<15 sec	<20 sec	<20 sec
t 90	<40 sec	<60 sec	<70 sec

Long Term Performance of the HygroClip S and C-94 Sensor

Mesurement System

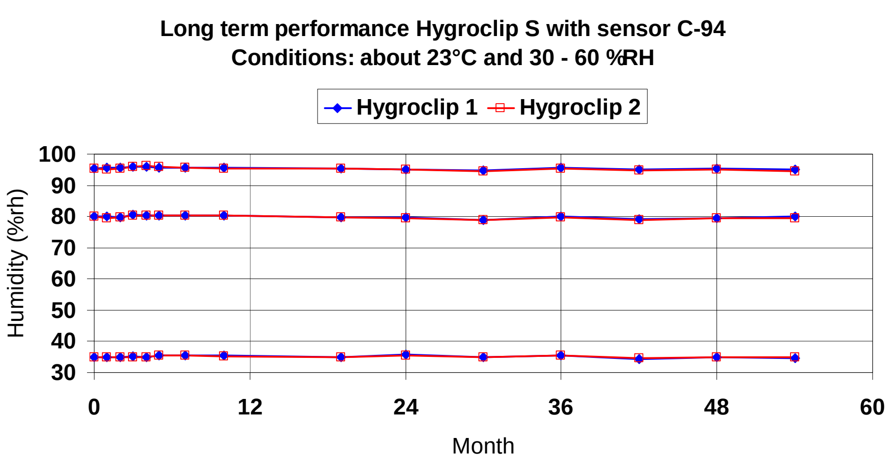
Reference:
Rotronic Humidity Standards



Test Method:
Probes in Rotronic calibration devices ER-15 with Rotronic humidity standards, situated in a WEISS climate chamber.

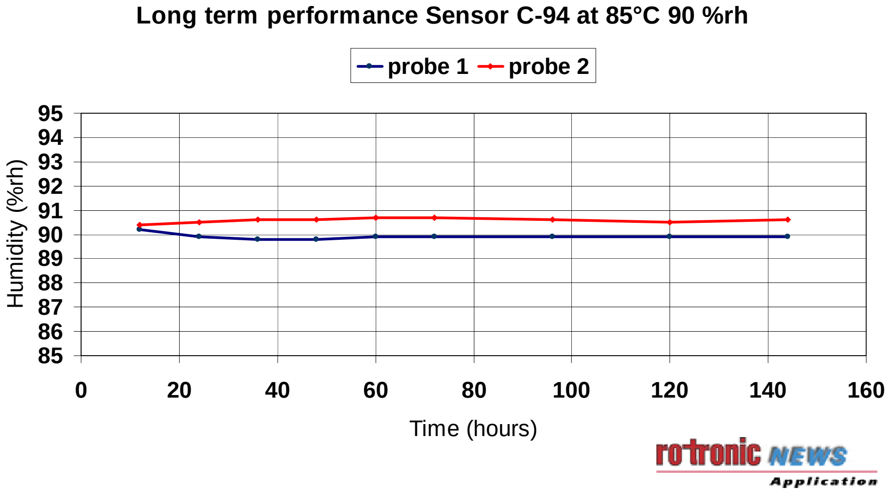
rotronic NEWS Application

1.1 Long term performance Hygroclip S

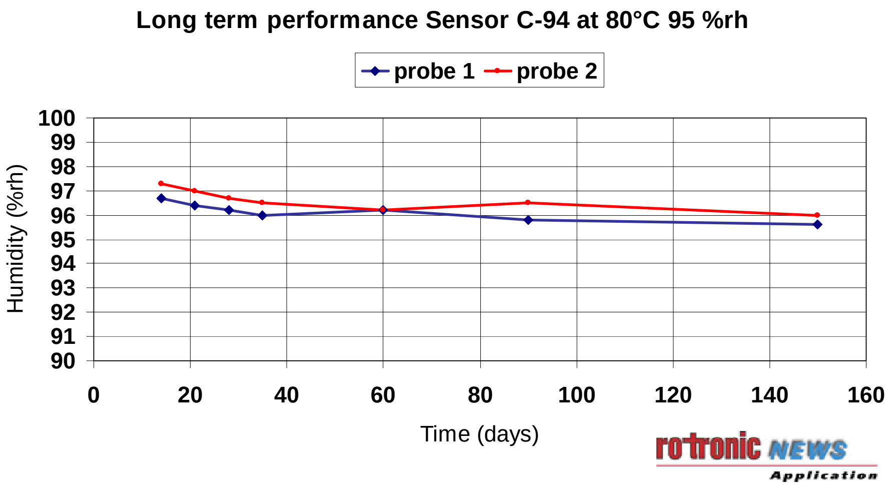


rotronic NEWS Application

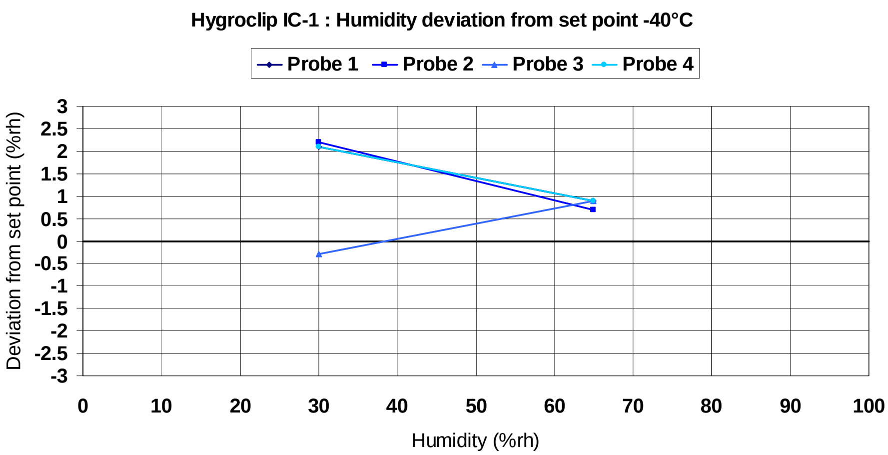
1.2 Long term performance Hygroclip S



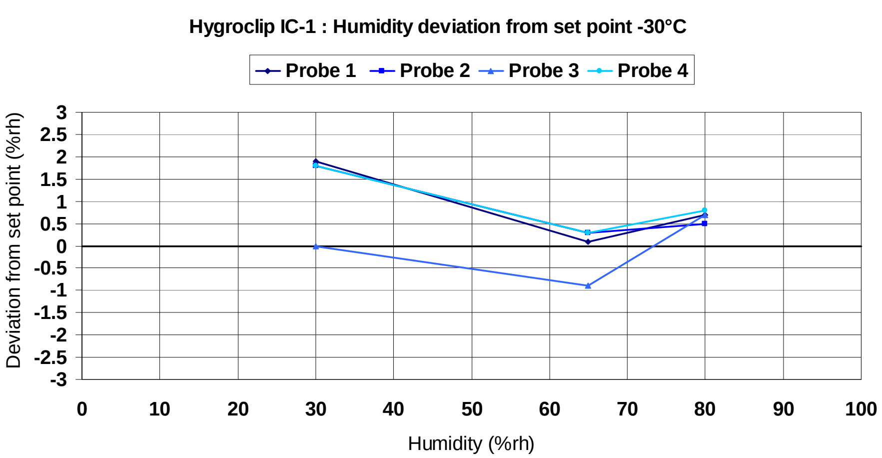
1.3 Long term performance Hygroclip S



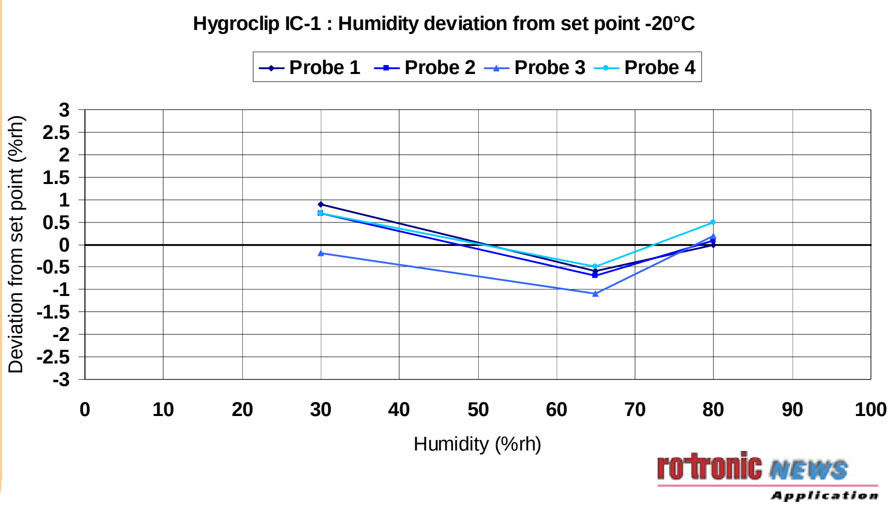
2. Performance Hygroclip IC



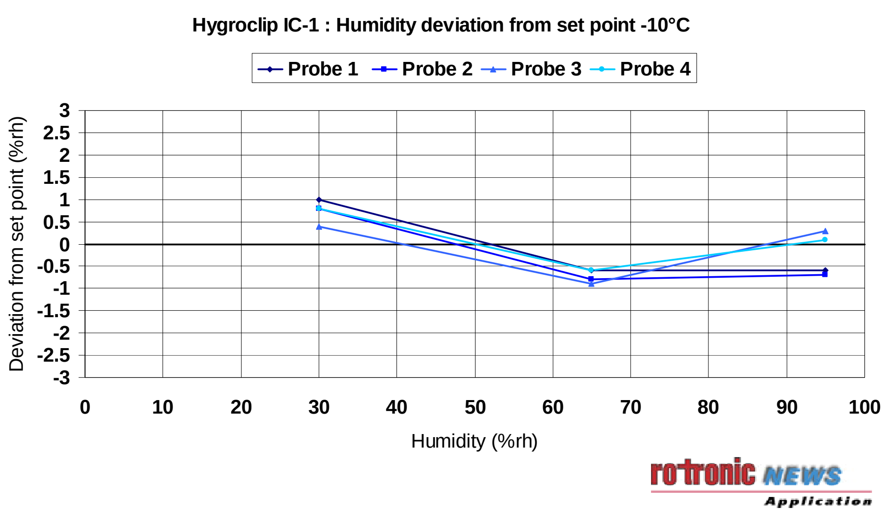
2.1 Performance Hygroclip IC



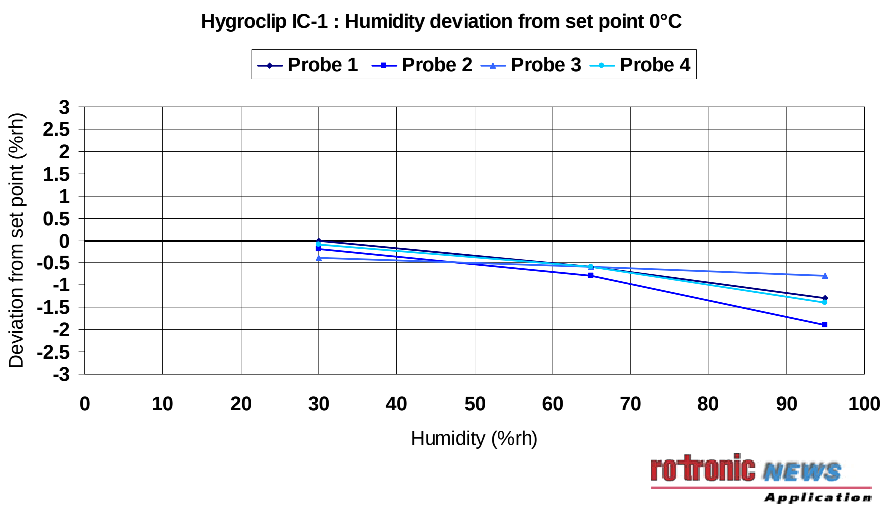
2.2 Performance Hygroclip IC



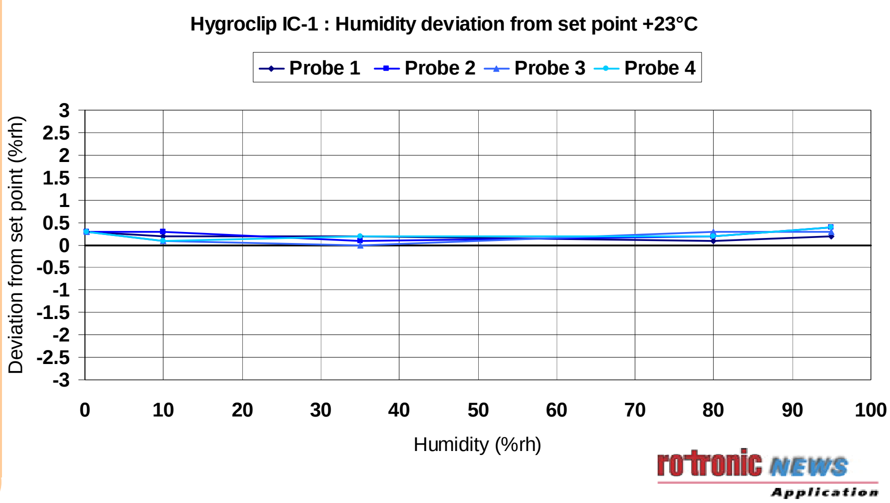
2.3 Performance Hygroclip IC



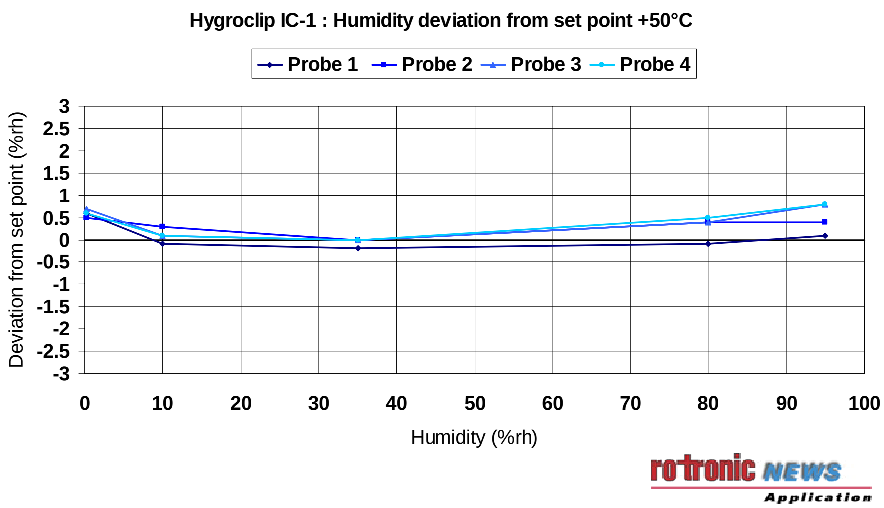
2.4 Performance Hygroclip IC



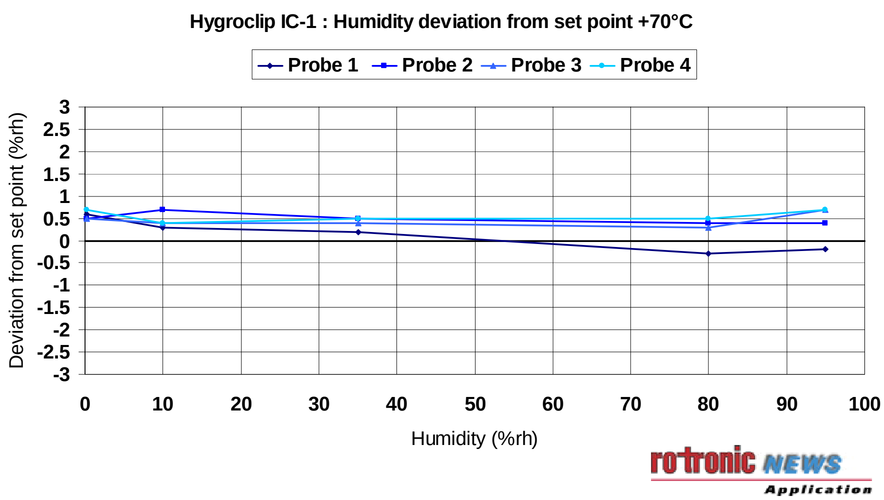
2.5 Performance Hygroclip IC



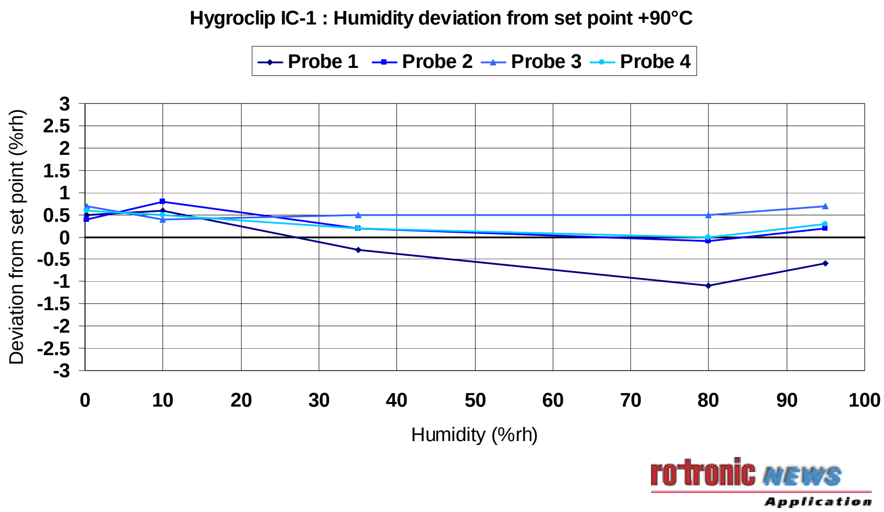
2.6 Performance Hygroclip IC



2.7 Performance Hygroclip IC



2.8 Performance Hygroclip IC



Application Stories and Tales

Application Stories and Tales

Last Long and Prosper (A water activity tale)

By: B. Auerswald
Food Quality Magazine, March/April 2000

Consumer demands and the growth of widespread distribution channels are driving food manufacturers to constantly devise ways to ensure product stability throughout extended shelf lives. Temperature and humidity are the key factors that accelerate physical and chemical changes in foods and thus bring about the end of shelf life. Manufacturing companies and their ingredient suppliers are increasing their testing regimens for these factors earlier in the product development cycle in order to anticipate and ward off storage and distribution conditions that can comprise product.

In an industry where competition is so fierce that a new food product might not make it to the store shelves, let alone into consumers' homes, food scientist and product developers have to carefully consider a number of attributes deemed desirable by the consumer. These attributes must work in concert and not compromise the quality or safety of the product. Further, virtually all organoleptic properties will change over time, making stability and shelf-life testing one of the most important tests conducted by food manufacturers. These companies need to ensure that when a product is consumed, say even six months after its manufacture, it is as palatable as the day it was made.

The underlying concept of any effort to extend shelf life is preventing or delaying the growth of spoilage microorganisms or the onset of chemical change. Along with microbial activity, there are a wide range of food deterioration mechanisms, including enzymatic changes, such as browning, pigment loss, vitamin degradation, chemical changes due to packaging, and flavor and aroma changes. These can all contribute in some way to making a product unappetizing to the consumer. Some of these can be alleviated or slowed by techniques such as the addition of organic acids, the use of advanced packaging materials or by modifying the environment inside the package.

Perhaps the two factors that have the most profound impact on product shelf life are temperature and humidity. Higher temperatures and humidity are virtually always harmful across the spectrum of food products. But it is often more than just a matter of lowering temperatures or reducing humidity; the relationship between these two conditions is interdependent and must be carefully controlled. For example, if a product, say a chocolate covered pretzel, is kept in 90% relative humidity (RH), then it will become stale. By the same token, if it is stored at 95°F, then the chocolate will undoubtedly melt. When the two conditions work together, usually in the presence of light, the result oxidation can complicate the situation even more.

"For oxidation to occur, you need three primary things: light, moisture and heat," says Julie Snarski, Manager of Application and Product Development for David Michael and CO., a flavor manufacturer headquartered in Philadelphia. "If flavors start oxidizing, we're in trouble. Say you have an orange cookie that you place in a pouch and store in a hot box. If the seal on the pouch is not right and the moisture is too high, and since you've already added the heat, you now have two things that cause oxidation. You're well on your way to a cookie that tastes like baby aspirin."

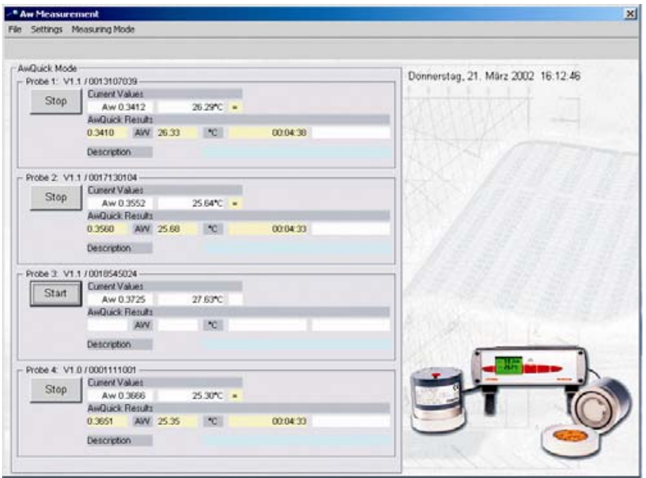
Ingredients and Interactions

The product development team at David Michael is well aware of oxidation and other ill effects humidity and temperature can cause, and they test for and guard against them diligently, whether during prototype design or product development. While the company does not manufacture flavors for retail sale, it does develop products for companies using the flavors it manufactures.

"We act as the R&D lab for many of our clients, as is the case with many flavor companies nowadays," Snarski says. "At times we develop all of the prototypes and the product, and other times our customers say, 'This is our cookie and we need a filling.'" An important specification for many of these companies is water activity (a_w), which is related to RH and is the ratio of the vapor pressure of water in equilibrium with a food to the saturation vapor pressure of water at the same temperature. A_w describes the degree to which the water is "bound" in the food and hence its availability to act as a solvent and participate in chemical/biochemical reactions and growth of microorganisms.

"The a_w level that we are looking for really depends on the product we're testing," Snarski says, "but we usually want levels in the lower end because of the nature of the products we test, such as candies, baked foods, fillings, frostings. Protein bars and snack foods." For example, a company might approach David Michael with its line of protein bars and ask them to develop bits for a new type of bar. The a_w levels of the bit and the bar must be tested. If there's a coating then test have to be done to see if it adds moisture and that the unequal moisture levels do not balance out after shipment to stores.

A_w testing is performed while the product is still on the small batch scale, usually less than 30 lbs., to allow for formulation changes, if necessary, Snarski says. "We use the information gathered from the a_w testing to take a look at how we can manipulate the formulas," she says. "If the a_w level is too high, we can use gum, starch, glycerin or maybe just add a little sugars to bind the water, depending on the product. Sometimes the a_w readings will be part of the flavor spec we give to a client, since many times we develop products for intermediate companies and they need the information for further development or for use in the QC."



In the lab, Snarski uses the A_wQuick water activity meter, from Rotronic in Huntington, NY, which can measure liquids, solids and powders with an accuracy of ±0.02 a_w (a_w is measured over the range 0.0 to 1.0). Price was the deciding factor for Snarski, through turnaround time and simplicity of use were also considered when she began looking for an a_w meter about a year ago. "We chose Rotronic instruments because I was familiar with their products and I knew it was easy to use," she says. "Usually the analysis time is about five minutes, which is important because our people handle 10 to 12 products a month and they don't have the time to wait for results."

Factors Affecting Stability

While moisture and humidity are recognized degradants to many types of foods and will impair shelf life, temperature can have a more widespread and deleterious effect on stability if not properly controlled. Observers say it is far more common for companies to assess the effects of out-of-range temperatures on their products than the effects of water activity. "Smaller companies tend not to test for a_w unfortunately, usually because it's not understood very well," says Theodore Labuza, PhD. Professor of Food Science and Technology at the University of Minnesota, St. Paul. "This is especially so because the concept of a_w is not taught very well in most undergraduate courses and most small companies do not have Ph.D working for them. The larger companies do a much better job of understanding and testing for a_w.

"In the near future there should be more people who understand a_w and actually test for it," says Labuza, who has done extensive research on water activity and shelf-life testing, and visits large food companies to update their employees on what is occurring in the realm of water activity. "In the 1950's the big concern with a_w was microbes and in the 1960's it was the stability of dehydrated foods. In the 1980's and 90's many people said that a_w is still a very important principle and that combining gas transmission with a_w will create a more stable analysis.

The shelf life of any food is determined by a product's least stable ingredient. During shelf-life of any food is determined by a product's least stable ingredient. During shelf-life studies, this limiting attribute is sampled from the product and analyzed at set intervals. This analysis yields a curve of functionality versus storage time, where the potency or integrity of the component is shown to degrade over time. Such information is used to set an end of life date for the product, or to allow product development scientist to make appropriate adjustments of the target component(s) to stay within specification up to the end of the product's life.

Stimulating Storage Conditions

Excessive temperatures will accelerate a range of chemical and biochemical reactions and thus bring on the end of shelf life. At David Michael, the effects of temperature are analyzed in both real-time and accelerated conditions, using a large incubator for accelerated storage, as well as a refrigerator for real-time studies. Typically, room temperatures samples are placed in their packages and stored for set periods of time, Snarski says. The timeframe for testing at David Michael depends on the customer specifications or on the type of product. Usually, the company performs stability test for six to 12 months, but has completed tests that lasted 18 months due to customer specifications.

“One type of testing we do is what we call our ‘Texas warehouse test,’ where we basically set up the test for the same conditions the product would encounter in that type of climate: lots of heat and humidity,” Snarski says. “Since it often happens that a product will be manufactured and shipped to all types of climates and conditions, it is very important we test for extreme conditions because it affects the acceptability of the product as well as the packaging.

“Testing for temperature is definitely critical, but as with everything else, it depends on the product,” she continues. “Take hard candy for example, if the candy has a low a_w as it should and is packaged well, temperature really doesn’t play a role. As long as there is no humidity to make the candy stick together, the temperature won’t make it melt – it’s already been cooked to about 300°F. But if you hold cookies or mayonnaise at 150°F, you will definitely have issues with oxidation and even rancidity. That’s where the Texas warehouse test comes in.”

Since temperature ranges are product specific the temperature range and the type of testing performed is dependent on the sample, says Mike Grob, Lab Manager Minnesota Valley Testing Laboratory in New Ulm, MN which performs shelf life testing mostly on raw meats and perishable fruits and vegetables. “If you have a raw meat product that is not brined or vacuum-packed and you store it at ambient temperature it will have a very short life,” he says. “It’s almost unrealistic to test meat at ambient or even accelerated temperatures because it goes rancid so fast. However, products like fruits, vegetables and some cheeses can withstand these temperatures.

Speed it Up

While product stability is tested throughout the development process and extended with the application of various processing techniques, product integrity is most subject to compromise in the storage and distribution system. Food companies commonly use elevated temperatures to conduct accelerated shelf life testing since it is generally the least complicated type of test method available and can often relate to actual temperature variations encountered during product distribution and storage. Accelerated shelf life testing is also often driven by marketing departments which are requiring product with extended shelf lives of a year or more to be developed in shorter time frames of perhaps only a few months. In order to meet the timetable, a means of estimating the product's end of shelf life must be utilized.

Generally, an initial step in shelf life testing is to identify potential modes of deterioration in the product based on an assessment of the factors that will influence product stability, such as product composition, packaging and environmental factors. Potential modes of degradation might include chemical changes, physical separation, color or flavor change, or nutrient loss. It is then important for the food technologist to select test methods that can accurately measure the degradative changes so that useful data is gathered.

Grob and his colleagues at MVTL conduct accelerated shelf life testing, in which storage temperatures are raised so that aging processes are accelerated. For example, storage at 30 to 33°C can give a two-to three-fold increase for many flavor changes; in particular, while storage at 35 to 40°C can accelerate oil or water separation four-fold and four to six weeks of storage at 55°C can cause pickle and sauce products to become unstable. Storage defects in frozen projects can be accelerated by storage at higher than normal temperatures, thus more rapid changes will occur at 18°C compared to the normal long term storage temperature of below -25°C, and still faster changes will occur at 10°C. Certain forms of deterioration, such as crystal growth and freezer burn, will also be accelerated if the storage temperature is made to fluctuate while the food still remains frozen.

For both real time and accelerated testing, MVTL's clients select the type of testing and the interval the samples are tested at. "Usually, we will be contacted by a plant manager, the head of the QC department or even a lab manager to perform the testing for their company, depending on their needs, Grob says. "We provide them with the dates, times-say one day, five days, two months-and temperatures we tested at, as well as the results of aerobic plate count or coli form testes that we may have performed. The results we present help our clients in a number of ways, including determining shelf life dates for the product.

Precautions and Possibilities

Some note that many people conducting accelerated shelf life studies don't fully utilize the data they collect, or don't collect the right kind of data. Different foods and their chemical components will react differently when subjected to different storage temperatures, so a universal acceleration factor cannot be used for all foods at any one storage temperature. Also some reactions that would not normally occur at standard distribution and storage conditions may be initiated at higher temperatures, resulting in inaccurate predictions for the shelf life of the product.

One problem that can occur when dealing with shelf life is the tendency to project the testing results and stability of one product onto another, especially when working with accelerated testing. Nancy Tregunno, applied Research Scientist at the Guelph Food technology Centre in Guelph, Ontario, has encountered this scenario. "One rule of thumb for shelf stable products is a two to three times acceleration at 33°C," she says. "Sometimes companies know what their acceleration factor is for a product line because of past verification studies. However, if significant changes are made to a formulation, or a new product is being studied, testing may be required to determine a new acceleration factor." This requires storing the products at both ambient and abusive conditions, and dividing real time shelf life by that obtained at high temperature/high humidity to get an acceleration factor; that is 12 months real time divided by four months accelerated equals three times acceleration factor.

If products are very similar in nature, perhaps only a few ingredients are changed that do not affect the stability of the product, then it is likely that the acceleration factor of the first product can be applied to the second one, Tregunno says. But if ingredient are added that make it more complicated, then the product needs to be re-evaluated for the acceleration factor.

At GFTC, which conducts contract research for food and packaging companies, shelf life testing is performed for manufacturers of a range of products, such as beverages, sauces and dressings, dry snack foods and condiments. High temperature and humidity are used where appropriate, but often it is oxidation that is expected to limit a product's shelf life.

Another problem that can arise during shelf life testing, especially when working with unrealistically high temperatures, is a change in chemical pathways, Tregunno says, whereby two compounds react to form another unexpected compound. To combat this, GFTC often sues high oxygen levels instead of high temperature to perform testing, especially when working with new packaging. "Often, our customers want to know what the shelf life of an existing product will be in new packaging, for example, when changing from glass to plastic which is increasingly common," Tregunno says. "We put the samples in a high-oxygen environment, usually around 85%. That gives us about four times the acceleration factor. Comparing the samples to a control allows us to identify a point in time when the sample will be considered different or unacceptable."

Whether testing a product in real time or at high oxygen acceleration, the trend is toward maintaining the safety stability and quality of product over longer periods of time, often with reduced usage of preservatives. “The need to extend shelf lives without using preservative definitely presents a challenge, but with the use of sound science, safe an effective processes can be developed, “Tregunno says. “If oxidation is occurring, we can add anti-oxidants and if necessary, we can add certain gums for stability. When we are dealing with different considerations and stabilizers, and even various conditions such as temperature, we work with different modifications of the formulation or recipe. There is mostly a scientific basis when it comes to the formulation of food, but there is definitely the element of art.”

Paper & Climate

Introduction

Modern machines for printing paper or cardboard, coating paper with aluminum and other types of unique applications are both fast and sophisticated. They are also quite sensitive, not only to the properties of the product to be transformed, but also to any variation of some physical phenomena. One of the parameters long recognized as influencing the properties of paper and cardboard has been moisture content. Equilibrium Relative Humidity is, together with the relative humidity of storage and work areas, responsible for any change which may occur in the moisture content of the product.

A recent study has demonstrated in the importance of Equilibrium Relative Humidity (%ERH), and some guidelines have been proposed. The narrow tolerances which are recommended exceed the capabilities of conventional hygrometers. A new generation of electronic hygrometers has been developed to meet these requirements.

Influence of Moisture Content on Paper

Moisture content influences a great number of physical properties of paper. The weight per surface unit, thickness and volume increase with moisture content. Changes in moisture content result in swelling or shrinking of paper fibers, while humidity cycles result impermanent dimensional changes as internal tensions in paper are released. Similarly, mechanical properties of paper, as well as printing properties, are influenced by the moisture content. Moisture content is therefore an importance production parameter which is normally monitored and controlled directly on paper machines.

However, this production parameter has relatively little practical significance for paper converting industries. As shown in the following paragraphs, many problems can be avoided if paper has the correct % ERH and if humidity does not differ from the ambient humidity. Moisture content must, of course, conform to the specified values; however, moisture content cannot be used to define the climatic conditions necessary to insure good conditions during paper printing.

Influence of Equilibrium Relative Humidity on Paper

Any difference which may exist between the %ERH of paper and the room relative humidity (%RH), results in changes in the moisture content of paper. These changes must be avoided or else problems will occur during the paper conversion or printing process. It is difficult to eliminate any difference between the ambient % RH and the %ERH, however, controls or limits can be established. A % ERH of 50% is ideal for paper since any changes, say from 40-60% will have little effect on the moisture content, (for cardboard converters 80% may be considered ideal). It has been determined that a large difference between a nominal 50% in paper and ambient air will cause a number of problems.

Static Electricity

From time to time, screen printers will experience difficulties due to static electricity phenomena, such as paper sheets sticking together. This happens mostly when the air is too dry and the paper is too dry. It has been found that when both the paper and air are in the 40-45% range this problem seldom occurs.

Dust Problems in Presses

Dry paper, more than moist, tends to generate dust. Sever dust problems in offset printing machines are due to the fact that the brittle fibers at the surface of the dry pager are easily detached. The result is the appearance of a dust layer on intermediary rolls causing poor printing.

Dimensional Changes of Paper during Printing

Vegetable fibers, which constitute the vase of paper absorb or desorbs water depending on the ambient relative humidity value. This water exchange results I n a swelling or shrinking of paper fibers, which affects the diameter of these fibers run parallel to the running direction of the paper machine. Accordingly, dimensional changes which are the results of moisture variations are more important along the axis that is perpendicular to the running direction of the paper machine, than along the axis parallel to it. At approximately 50% ERH a humidity change of 10% ERH results in a change of typically 0.1-0.2% in the length of the paper. Such a humidity difference gives a dimensional variation of 1 to 2mm on a 1x1 meter paper and therefore probabilities of poor, inaccurate printing due to positioning problems are high.

Paper running through an offset press usually gains water as it is moistened in the process. The change in the moisture content depends not only on the % ERH of the paper (40-60%), but also on the ambient %RH. An institute which has made a study of properties of paper and printing in Europe ran a test on two different offset presses and, based on results, have determined that the difference between % RH should not be more than 10%. Within this range the dimensional changes will remain at a constant level because the moisture of the paper will not change by more than 1%.

The same indication has been observed when using other types of presses, such as in screen printing, where the paper is not moistened and tends to lose water as it experiences heat.

It must be pointed out that all difficulties experienced with poor paper positioning are not entirely due to incorrect humidities.

Deformations of Paper Due to Humidity

Paper in stacks or rolls shows deformation if too much moisture is exchanged with the surrounding air through the edges of the stack or roll. This is due to the uneven distribution of this moisture as it is exchanged with the ambient air during storage or transport. Water-vapor-tight packaging protects the paper and it should not be removed without first checking % ERH of paper and % RH in the ambient environment. Differences up to ±5% RH will not cause problems, while a difference of 8-10% RH now becomes critical.

When difficulties are expected due to a large difference between % ERH and % RH then certain measures should be taken either to adjust the %RH to a correct value, as by air conditioning, or to progressively condition the paper to the ambient RH. In the case of paper stacks, individual sheets may be eventually conditioned by full exposure.

It has often been commented that the printer or paper converter does not have the time to condition the paper to the room environments. The paper must come in and get out. But, is this really the way? Paper stored at a mill or distributor is at a specific level, then during transport it goes through different climatic changes. When the printer gets the paper he assumes it is exactly as it was when leaving the paper mill. With the quality control procedures of the mill, very careful attention is paid to the correct moisture content of the paper that is ordered. In many mills the %ERH is also carefully monitored before the protective wrapping is placed on the roll or stack. However, it is not possible to have final control until it reaches the printer. For this reason, many mills will have their technical service people go out to the printer and try to assist him in determining where the problem exists, i.e., paper, room, storage area, etc. Many technical reps also have a sword probe or similar unit which allows them to test the paper and the room for differences in humidities. Obviously, if it is a condition to be checked by the technical a representative, it also is a point which must be considered by the printer.

Deformation of Paper Due to Temperature

Temperature exerts a minimal influence on paper; however, any large temperature difference between the paper an the ambient air will have almost the same results as a humidity difference. This is due to the fact the % RH in the air layer in the immediate surroundings of the paper stack or roll is modified by the paper temperature. Assuming an ambient air of approximately 50% RH, a temperature difference of ±1°C will result in a humidity variation of ±3% RH. Thus, it can be seen that when temperature differences approach 3-4°C, problems can occur.

Once again we have the differentiation of moisture content and % ERH. The temperature will have little effect on the moisture content, even at values which are 20°C, yet the humidity changes at lower values and problems occur. Perhaps the printer or paper converter doe not take this into consideration either.

Large temperature differences between paper and storage or work areas easily occur in winter or summer due to transportation of the product. Without air conditioning, the temperature variation between storage and work areas may be 10-20°C on a summer day. A stack or roll of paper can adapt to this variation, but very slowly. At 45% RH, a difference of 5°C between the paper and air creates a % RH of 60%, thus exceeding the recommendations of 10% without even getting to the press!

Paper should be kept in its vapor-tight packaging as long as a temperature difference exists. An equilibrium time of 24 hours for each 10°C temperature difference and cubic meter of paper is recommended.

Curling of Paper Sheets

Paper fibers does not all run exactly in the same direction across the thickness of a sheet of paper. Very large moisture variations will result in unequal dimensional changes on both sides of the paper sheet, therefore curling occurs. This is more prominent problem with coated stock, since both sides of the paper are not similar. When working with such paper, minimal effects can occur with humidity variations of less than 10% RH.

Drying Time of Printing Inks

High values of %ERH as well as low temperatures result I n long drying times after printing. Experiments on offset presses have shown that a % ERH of 60% and a temperature of 20°C are practical limits for acceptable drying times.

Recommended Values of % ERH

There is no optimum value of %ERH which would be valid for all paper and cardboard converts and printers. The printing industry normally requires % ERH in the range of 50-60%, while cardboard converters require an ERH of about 80% which allows them to form their product easier. The packaging industry, on the other hand, will require another value of ERH.

Since paper and cardboard mills cannot deliver their products at an exact ERH, a compromise must be established. A nominal value of 52% ERH for paper and 80% ERH for cardboard seem to be the general rule to live with.

Recommended Tolerance of % ERH

Again we have to make a compromise. Here a ±6°RH seems to be accepted by mill and user. Also this value is recommended by the European institute previously mentioned.

Summary

FOGRA (The German Research Institute for Printing and Reproduction Techniques), from which most of these figures and facts have been obtained, has done testes on many machines and instruments. Based on these tests their recommendations have been developed.

Now that the numbers have been established, how do the printer and paper converter put them to use? Obviously, suitable instruments must be made available to perform these measurements and at the same time not cost larger amounts of investment. The unit must be easily handled and should provide quick measurements so that the user will not be waiting for hours to determine suitability of the roll or stack.

The old fashioned saber probe was too difficult to handle, required calibration often and was also very slow in response. Modern technology has created a new probe which is inexpensive, light in weight, provides quick and accurate readings and is simple to use.

Automotive Test Chamber Features Rotronic-Transmitters

Rotronic Humidity News - Issue: 1/2000

Performance Surpasses Expectation!

Clive Hurley Environmental Engineering is one of the world's leading manufacturers of environmental test chambers. A recent installation at the UK's leading independent automotive development center, LTC, featured a Rotronic I-2000 industrial humidity and temperature transmitter.

Traditionally, Clive Hurley's has employed wet an dry bulb psychometery for humidity Measurement duties, due to the wide operating range of LTC chamber, a Rotronic I-2000 transmitter was installed.

Andrew Hurley, director commented, "Obviously above 100°C and below 0°C, wet and dry bulb humidity measurement is not practical, and our customer needed to know the humidity value over the chambers full working range. The Rotronic I-2000 offered the widest available temperature range so it naturally became our preferred choice. Once installed, we were really impressed with the accuracy stability and response times it provided."

The LTC test chamber is designed to cope with vehicles up to the size of a truck tractor unit, with internal dimensions of 3.3 x 4.3 x 6.3 length and a load capacity of 8 tons! The temperature range is –40…+120°C, with a humidity capability of up to 99% RH over the temperature range of 10…70°C. In addition, full solar capabilities are incorporated so that an extensive range of real world conditions can be reproduced. One company who has already made use of the LTC chamber is sports car manufacturer TVR.

The Rotronic I-2000 transmitters are available in a wide range of configurations to suit almost any application. Maximum measurement ranges for the I-2000 are 0…100% RH and 50…+200°C, with operational exposure to –75°C not affecting the sensors.

Oresund Bridge Maintenance Cost Slashed

Rotronic Humidity News - Issue: 1/2000

Rotronic humidity instruments have slashed corrosion protection costs on one of Europe's largest civil engineering projects.

The Oresund Bridge will physically link Denmark and Sweden for the first time. Most of the major construction has not been completed. The bridge's weight bearing support structure, comprised of steel girders, will feature a corrosion protection system that will be monitored by Rotronic humidity instruments.

With an internal volume of over 120,000 cubic meters cost effective corrosion protection was critical within the hollow girders. Nine Munters' air dryers have been installed to keep relative humidity below a level where corrosion of the steel can occur. The dryers are controlled by a series of Rotronic MP400 probes, whose wide operating range and excellent long-term stability are essential for the correct operation of the system.

Stig Fristad, project leader at Munters, says, "Experience from a similar project (Hogakusten Bridge in Sweden) showed that over several years the cost of running the air dryers is approximately 1% of the cost of traditional corrosion protection schemes.

The accuracy and stability of the Rotronic sensors is an important factor in keeping humidity levels, and therefore energy consumption under control.

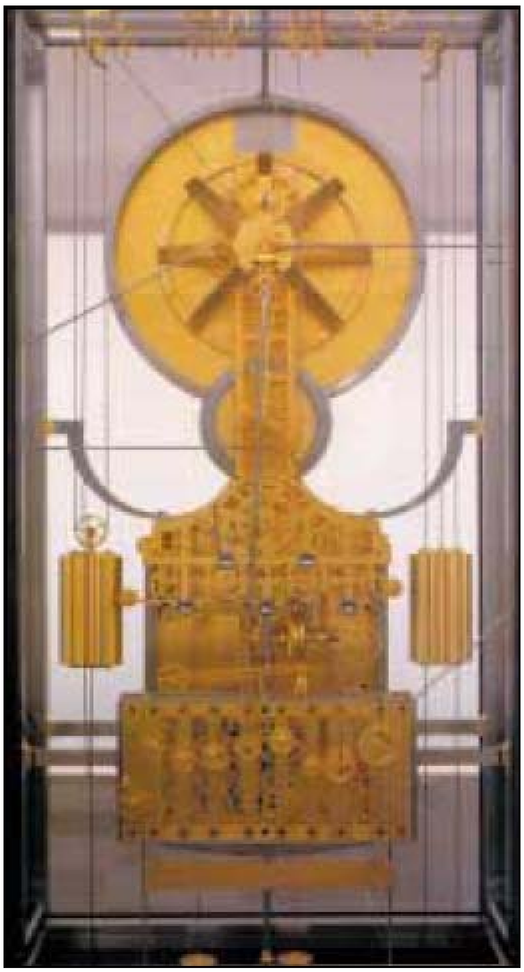
There are in total 18 MP400 installed in this application, 16 are used for the control of the air dryers, 2 are used purely for monitoring purposes, the measurement data can be viewed by both the Danish and Swedish authorities.

Jens Olsens’ Worldwatch in Copenhagen

Rotronic Humidity News - Issue: 1/2000

Jens Olsens’ Worldwatch on Copenhagen’s city hall is known by most Danish people and internationally as a unique astrological clock. The clock consists of 15,448 parts in 12 mechanisms. Apart from the time around the world, the clock shows the time of each sun rise and sun set, the year, the weekday, the date, the month, the sun & moon rotations, and the planets movements.

Renovation Necessary



Jens Olsens’ Worldwatch was started in 1955 and was functional until 1995, when the clock was disassembled. It was stated that the mechanisms had become inaccurate and renovations were necessary. The display case that held the clock partially protects the works against dirt and environmental conditions. But it was obvious that this protection was inadequate. Several of the mechanisms were affected by corrosion, which prevented correctly operation. After two years of intense work, renovations were finished in 1997.

Munters Dehumidifier Ensures Conditions

It was examined how you could best protect this valuable work from the air’s destructive effects. Since the main problem was corrosion, caused by high humidity, the choice was dry air preservation by the means of an absorption dehumidifier from Munters. A dehumidifier type ML 180 was built in with the room’s ventilation system to ensure the air condition in the showcase is kept constant. The showcase receives a constant 25 m^3/h volume of air at 18°C and a relative humidity of 40% RH. The dehumidifier is controlled with the ventilation system through a CTS system. To prevent air from the outside from entering the showcase an elevated pressure is maintained in the showcase. The showcase is equipped with Rotronic humidity and temperature sensors in each side of the clock box. By keeping the relative humidity at only 40% RH corrosion is prevented. The clocks stable operation after the renovation is expected to continue for many years since the delicate mechanism is no longer affected by the surrounding air.

Munters Leading Dry Air Supplier

Munters is a leading international supplier of dry air solutions. They have delivered dehumidifier systems for many similar conservation purposes and are a well known name within and among others and museums around the world. Many storage rooms, depots and warehouses today are equipped with Munters absorption dehumidifiers. At low temperatures these absorption dehumidifiers assure good and dry storage conditions for valuable items. Munters in addition supplies to the process industry where production environments are dependent on a constant and low humidity year around.

Cool Application for Rotronic Humidity Technology

Rotronic Humidity News - Issue: 2/2000

The CTS Company is concerned with the design, manufacture and the distribution of high quality devices and systems for environmental simulation, as well as refrigeration and air conditioning. Under the management of three partners with many years of experience in environmental simulation and climate technology, CTS employs around 50 staff and continues to expand, and now operates world wide with a reputation for high quality products.

The CTS Climatic C-20-200/S provides very high accuracy over a wide temperature range and uses a Rotronic I-2000 Industrial Humidity and Temperature transmitter, which has an operational range of 0 to 100%RH and –50 to +200°C.

The system's optimized CTS control unit, combined with precise measurements provided by the Rotronic I-2000, provides a very large performance range which does not stop at the simulation of polar climate. "Previously, that was a problem.", says Sales Director, Dipl. Ing Helmut Maute, who further states, "In the range below the freezing point, many measuring methods are completely useless, or very inaccurate. Our customers include, amongst others, well known manufacturers in the automobile industry, where reliable and exact measured values offer the entire range are especially indispensable. With the Rotronic industrial transmitter (I-2000) we have found a product matching our high demands for measurement accuracy and long term stability. The I-2000 perfectly covers the working range of our climatic cabinets and has additional reserves."

The climatic cabinet C-20/200/S has a temperature range of –20°C to +120°C and a humidity range of 10% to 98% RH. Thus all of the world's climate zones are fully covered taking account of the seasons and can also be simulated over long periods.

Abbey Library St. Gall

Rotronic Humidity News - Issue: 2/2000

The Abbey Library of St. Gall is the oldest library in Switzerland and one of the oldest and most important monastic libraries in the world. Constant humidity and temperature conditions are essential for the storage of books. Thanks to its reliability and its easy application the Abbey Library St. Gall uses the HygroLog Humidity Temperature Data Logger of Rotronic. HygroLog stores humidity and temperature values in user defined intervals, data is easily downloaded to a PC via a RS-232 interface.

Its unique collection of books reveals the development of European culture and documents the cultural achievements of the monastery of St. Gall from the eight-century to the dissolution of the abbey in 1805.

Numerous works, fundamental to the history of European thought, have been transcribed in these manuscripts and are well preserved within the library. The Abbey Library along with the entire abbey precinct of St. Gall was included in the UNESCO list of global cultural heritage site in 1983. At the core of the library's collection is the largely indigenous corpus of Carolingian and Ottonian manuscripts from the eight to the eleventh centuries.

Today the Abbey Library is part of the Catholic Administration of the State of St. Gallen. A modern scholars library, specializing in the medieval period, it is also one of the leading museums in Switzerland. Every year some 100,000 visitors from all over the world view the exhibition in the renowned baroque hall; considered one of the most beautiful library rooms in the world.

Rotronic Conquers the Jungfrauhoch

Rotronic Humidity News - Issue: 2/2000

The Jungfrauhoch in Switzerland is one of the most popular and attractive excursion destinations and Alpine vantage points. At the beginning of the 20th Century, the Jungfraubahn project – a railway between the famous Wengernalp and the Jungfrauhoch at 3454 m (11'333 ft) above sea level, was finished and officially opened to the public. Thus it became possible to install a scientific laboratory, where since 1931 astronomers, astrophysicists, geologist, meteorologists, hydrologists and physicians work under the high alpine conditions in very clean air. Avalanche research, general weather information, as well as other data has been collected here. There's even a solar laboratory.

Instruments for measuring relative humidity and temperature must be able to withstand the harshest imaginable environmental conditions: direct sun and high UV radiation in the daytime, fierce and bitter cold at night and during winter, thunderstorms, blizzards and heavy snow, and last but not least very high wind speeds.

The reliability of the Rotronic sensors installed on Jungfrauhoch is assured, with the exception of occasional calibration (recommended once a year), there is almost no maintenance required.

The Holy Shroud - The Wounds of the Passion

Rotronic Humidity News - Issue: 2/2000

A century ago the Shroud generated excitement when it was photographed in 1898 for the first time by Secondo Pia. The negative of that photograph revealed in detail and with even greater clarity than the positive image all the wounds that the shroud preserved. How was the image of the Shroud formed? Science has not yet come up with any plausible explanations.

Since 1998 the Shroud has laid horizontally on a sliding support inside a ballistic steel shrine with safety glass. Inside the shrine the inert atmosphere (Argon with 0.5% oxygen) prevents the generation of anaerobic organisms. What is important is that the flax fibers are kept under the same conditions, which they have been for centuries. The humidity and temperature is measured with the I-1000 device by Rotronic. Humidity values are controlled between 50…60% RH at 20°C.

The man whose image appears on the Shroud was crucified in the same way as Jesus and details of the wounds which appear on the Shroud correspond to those described in the Gospels. The Shroud is an image to be looked at and contemplated.

For believers it is an "Icon of the Passion" as defined by Pope Paul VI. The wounds of the Passion of Jesus are the reason for so much interest in the shroud, and explained its veneration since ancient times.

A Difficult Piece

The Shroud is a linen sheet, 4.36 meters long by 1.10 meters wide. Two dark parallel lines with the white triangles, burn marks (from the Chambery fire in 1532) and the imprint of an image of the front and back of a man who died from crucifixion are clearly visible.

The Public Shroud

The shroud is shown only on special occasions. From 12th to 22nd October 2000, the Shroud can be seen in Turin. It is the longest exhibition time for the shroud in history, and only the sixth time it has been displayed in the last 100 years.

Measuring Water Activity at the “Millennium Seed Bank”

By: Chris Birch
Rotronic Humidity News - Issue: 1/2001

The Royal Botanic Gardens are using a range of Rotronic Instruments to monitor the free or available moisture (water activity) of seeds stored at the Millennium Seed Bank, Wakehurst Place in the South of England.

Sponsored by the Millennium Commission, Orange PLC and the Wellcome trust, the Millennium Seed Bank is an important conservation and research facility storing live seeds in suspended animation for possibly thousands of years, acting as a safe depository for the world’s wild plant species. Due to the ever increasing spread of humanity, the focus is being directed toward those wild plants most in need of conservation, mainly in tropical dry lands. The seed bank hopes to preserve around 25,000 plant species by the year 2010.

Scientific information obtained from the many rare seeds will be registered on a comprehensive data base, which will be made available to universities, agricultural bodies and organizations in the developing world, thus publishing the contents of the seed bank.

For this ambitious project to be successful the seeds have to remain viable, they are required to germinate after the significant periods of storage involved. Seeds are collected in collaboration with Kew’s overseas partners. The seeds are rapidly shipped back to the Seed Bank, where they are separated from their seed casing and dried to 15% Equilibrium Relative Humidity (ERH). They are then frozen and placed in air tight containers for storage at -20°C. Because of the very low temperature and moisture contents the seed’s ability to germinate is suspended. To ensure that seed remain in this state, the artificial environment is monitored very carefully, and a sample of each seed is taken periodically and tested for germination, confirming they are still alive. By caring for the seed in this way, their life span is increased dramatically they are expected to survive for hundreds and some times thousands of years!

Rotronic Instruments provide an exact measure of the Equilibrium Relative Humidity of the seeds before and during storage they have a high accuracy of ±1.5%rh, ±0.3°C at 23°C. They are specially designed to be fast and easy to use and with a very low drift specification all Rotronic Instruments remain accurate over long periods of time.

Keith Manger, the Laboratory Manager for Kew's Seed Conservation Department said, "The seed bank routinely uses a range of Rotronic Instruments for research and general seed sample measurement. We have worked closely with Rotronic to develop our measurement technique".

Products used include the AWVC measurement head with BT-RS and the new HygroLab display unit.

The New Treasure Chamber in Cologne’s Cathedral

By: Roland Scheurich
Rotronic Humidity News - Issue: 1/2001

After six years of planning and construction, a new treasure “chamber” exhibition in Cologne cathedral sacristy opened in autumn 2000. The exhibition area now extends onto three levels and stretches over 500 square meters. Just entering this unique historical area with a view of the original Roman town wall is well worth a visit.

The treasures belonging to the church include shrines, relics, and many types of accessories used in holy service such as chalices, monstrance’s, crosses, censers, bowls for chrism and many more. Examples of the crosier, chest crosses, and other insignia of the Archbishop of Cologne, as well as chasubles, are also included in the cathedral’s treasures. Discoveries from the Franconian graves and examples of the cathedral’s high quality sculptures from the middle ages are shown for the first time in the new exhibition.

The concept of the exhibition was developed by the directors of the cathedral’s building archives, Dr. Rolf Lauer and Dr. Leonie Becks, in cooperation with the exhibition’s organizer, Ingrid Bussenius.

In order for the valuable displays to be sufficiently protected, the Kieler Company “Glas + Spiegel Schulz” has been entrusted with the design and manufacture of high quality and technically complex display cases. For humidity and temperature measurement, the HygroClip from Rotronic was selected. Its compact construction, interchangeable service concept, modular design, combined with high accuracy and excellent long-term stability made it the natural choice. The religious and historical importance of the treasures meant that only high quality products are specified for use in the exhibition.

The objects are superbly presented through non-reflective glass and the display cases feature customer lighting by specialist designer Daniel Zerlang-Roesch. The costs for the construction of the treasure chamber amounted to around 15 million German Marks, not including the costs for building renovations.

Rotronic HygroLog-D: Data Loggers in Church Organs

By: Peter Muller
Rotronic Humidity News - Issue: 2/2001

The protection of cultural-assets is a much discussed topic. Various environmental pollutants damage irreplaceable cultural possessions. Humidity is certainly one of the factors which can irreversibly damage these precision made objects. Obviously, it is of great importance to avoid such damage. However, the people responsible for such instruments often don't know the climate conditions of their premise. Rotronic data loggers help to obtain the data needed to preserve these ancient treasures.

Within the area of preserving church organs, the Swiss company, Christoph Metzler Orgelbau, also known as "The Flying Registers", have been doing pioneer work since 1995. Christoph Metzler is a 4^{th} generation organ builder. His company is located in Dietikon, a suburb of Zurich, and works together with 5 partner companies of the "IG Orgel", covering all Europe as well as the United States. It is their common goal to preserve old organs and to restore damaged ones. Their objective is to preserve the instrument(s) in its original condition, as best as possible. Unfortunately, as time passes by, many organs are altered and partly reconstructed; some of them over and over again. Chritoph Metzler says, "With every change, an organ loses some of its character." The changes were usually made when the spirit of the times changed, often also with the change of an organist. Many organs had to be replaced due to failed reconstructions.

Now, what happens to an organ when the climate is wrong?

If the moisture content becomes too high, the wood starts to swell; if it's too low, it shrinks. These actions may easily destroy the glued junctions and in extreme cases even lead to the ripping of the wood itself. If the wood swells, the organ is no longer easy to play. The reaction time of the various components is not correct anymore; the organ does not sound good. Obviously, this effect results in a loss of value, and it seems rather logical, that many alterations and reconstructions of old instruments have been done for that reason.

So the goal is to prevent the instruments from being damaged or even destroyed. Obviously, it is much easier to prevent than to repair. The humidity should always be in a range of 50…60%RH. Using the HygroLog data logger the conditions are easily recorded.

Since the beginning of 2001, Christoph Metzler has used Rotronic HygroLog D data logger, which is placed inside the organ and records the climate data autonomously for long periods of time. Humidity and temperature data provides information which correlates to the reasons of eventual damages. Even if there is no damage, the data recorded give us information on the climate; thus showing whether or not the premises should be heated, ventilated or air conditioned. Once the data is known, it is also easy to determine whether or not a claim for warranty is justified. And of course, this is a simple task for a Rotronic HygroLog.

Application: Pyramid of Saqquara Egypt

By: Irmina Sibilska, President B&L International
Rotronic Humidity News - Issue: 2/2001

The Great Pyramid at Saqquara, on a desert plateau some 30 km south of Cairo, is the site where the Egyptians first tried to put into practice, on a massive scale, their attempt to defeat time and death by building tombs and temples in stone. It is here the Egyptians built the world's first pyramid, part of an extensive funerary complex for the Pharaoh Zoser. The Step Pyramid, (a stairway to heaven for the departing Pharaoh), some 62m high, is central to the complex and was constructed 4500 years ago. It is older than the more famous pyramids at Gizeh and the Sphinx, and had already been standing for over a thousand years when Tutankhamen came to the throne around 1500BC.

A New Discovery

Archaeologists have been excavating the site for over 150 years. But up until 1987 no one has explored the desert area on the complex's western side, as archeologists believed there was little to be found there. However, an archaeological mission led by Professor Karol Mysliwiec, working on behalf of the Centre of Mediterranean Archaeology at Warsaw University, discovered burials spanning nearly 4,000 years, one of which was the well preserved and colorful tomb of a powerful Egyptian politician, a previously obscure vizier name Fefi.

A Vizier was the right hand man of the pharaoh. Fefi seems to have been a colorful character that lived in the 24th century BC. The tomb's walls inscriptions portray him cavorting with woman known as "The One Who Loves Life". His five wives apparently were stuck at home. He lived late in the reign of King Teti, first ruler of the Sixth Dynasty, a time of turbulence. Fefi controlled much of the nation's financial and administrative affairs. The 1987 excavation found deep shafts hewn in the rock, many mummies and a wall running parallel to the pyramid, which seemed to be part of a monumental tomb. The team returned to Egypt in 1996, as part of a joint Polish Egyptian expedition with the Supreme Council for Egyptian Antiquities.

It unearthed the courtyard of the tomb, discovering a leveled rock surface covered with a thick layer of mud. When this mud-brick rubble was finally removed, the team found colorful relief's decorating the entrance to a funerary chapel showing the tomb's owner in the company of a lady.

Need for Preservation

The extremely fragile structure of the local limestone causes salts to concentrate on the paintings. This poses challenge to conservators from the National Museums in Warsaw and Krakow. Conservation will take years of hard work. The work depends greatly on climate conditions inside the tomb. Of particular importance is monitoring changes in humidity conditions over time, between successive archaeological digs. To achieve this accurate and stable data acquisition equipment was needed to collect as much temperature and humidity data as possible.

Technology Assists

In desert conditions humidity and temperature can vary widely over a 24 hr period, including excursions to high humidity and high temperature the worst type of environment for electronic instrumentation. The product of choice for this demanding application is the Rotronic HygroLog, supplied through Rotronic's Polish distributor – B&L International Warsaw.

HygroLog is a self contained modular logger featuring the interchangeable HygroClip sensor module. When calibration or maintenance of the measurement hardware is required the site personnel can simply fit a pre-calibrated new module within seconds. Continuous collection of valuable climatic data is therefore guaranteed and the conservation team is able to precisely record the conditions to which the reliefs are exposed. From this data decisions can be made as to how the paintings need to be treated to prevent further deterioration, and therefore preserve this priceless record of the past for future generations.

Rotronic Sensors on Kilimanjaro

By: Gary Moliver
Rotronic Humidity News - Issue: 2/2001

The first European sighting of Kilimanjaro occurred 62 years after the ascent of Mon Blanc. Yet, reports of snow and ice high on the mountain were viewed for many years as an apparition. We now know that the massive equatorial volcano in Tanzania, with a summit elevation of 5895 m (19,341 ft), supported ~20 km^2 of glaciers until late in the 19^{th} century. By last year, the ice-covered area that Johannes Rebmann described as "dazzling whiteness" in 1848 had decreased by ~90%, to 2.2km^2.

Today researchers are actively investigating the meteorological conditions of Kilimanjaro to better understand the relationship between the mountain's climate and the demise of its beautiful tropical glaciers. An automated weather station was established near the summit in February 2000, employing Rotronic MP101A probes to measure humidity and temperature. Data are stored on-site and transmitted via Argos telemetry to the University of Massachusetts. Rotronic probes continue to provide accurate measurements despite severe conditions including perpetually sub-freezing temperature and solar radiation often in excess of 1200 W m-2.

Further details on the weather station and Kilimanjaro climate research are available at: www.gejo.umass.edu/climate/kibo.html

Rotronic Measuring Equipment in Nuclear Research

By: Carl Welinder
Rotronic Humidity News - Issue: 1/2002

Radioactive waste from nuclear power stations needs to be stored for 100,000 years before radiation levels reach that of naturally occurring Uranium. After 1000 years, the direct radiation will have declined to a harmless level. According to Thomas Karlsson at SKB (Swedish Nuclear Fuel and Waste Management) time is the most critical factor in our project to develop a storage method for highly radioactive waste.

The Adpo Hard Rock Laboratory is a center for research on the storage of nuclear waste. Its construction began in 1991 with a shaft 480m down into the hard rock outside Oskarshamn on the east coast of Sweden. At this depth, 8m x 1.75m diameter holes were drilled into the solid rock each contains one canister (4.83m x 1.05m diameter, 27 tons). Instead of waste, a 1800 W heater is installed inside the canister to increase the temperature in order to stimulate the presence of nuclear waste.

The waste itself is very non-reactive and is unlikely to contaminate ground water, but a series of additional barriers are used to prevent leakage. First level of encapsulation consists of cast iron, which is then enclosed within a 5cm thick copper container. Filling the gap between the metal canister and the hard rock is a layer of clay.

To explain the thinking behind the method, it is necessary to consider evidence from historic natural occurrences (man-made radioactive waste has only been produced in the last 60 years). Two billion years ago in West Africa nuclear reactions occurred underground and produced several tons of radioactive waste. Investigations have shown that radioactive isotopes permeated only a short distance through the rock structure, which shows that certain rock can be a good containment material.

One factor of high interest is the clay’s ability to absorb water from the surrounding rock. When clay absorbs water it expands, which in this application causes an increase in pressure around the canister. The fully saturated clay seals the canister from oxygen that might cause corrosion. The research required a measurement of the moisture level present within the clay between the hard rock and the canister. By recommendation from international researchers Rotronic sensors were specified as being accurate in long cable high pressure and high temperature applications. In addition custom filters and seals were designed. In September 2001 measurement started.

So far, the Swedish nuclear power industry has produced 5000 tons of highly radioactive waste. According to a plebiscite, the nuclear power plants in Sweden will all be shut down and 4000 canisters with two tons of waste each will need to be buried and sealed, with completion by 2050. In case a future generation would like to recover the waste and reuse it a concurrent project is running to test canister retrieval methods. For each kWh of energy produced in the 12 Swedish nuclear power plants, 0.001-0.002 Euro is allocated to pay for the future storage of radioactive waste. This fund is also financing the research at SKB, as well as other projects in Germany, United Kingdom, Finland, France, Japan, and Spain who also run their own projects at Aspo Hard Rock Laboratory. For instance Spanish scientists are monitoring possible movements of the canisters as the clay expands.

The picture to the left is taken at a depth of 480m, and shows from left to right, Carl Welinder from Rotronic's distributor in Sweden Swema, electronic engineers Thomas Karlsson, from SKB, and Sten Johansson from the site's electrical contractor, JL Elektronik. In the middle- Rotronic's cabinet for electronics of the 95m cable, 10 bar pressure resistant humidity and temperature probes. At the top, drilled holes for the sensor cables are shown, these lead to a clay and rock filled tunnel. In the tunnel, holes for canisters are drilled in the tunnel floor. Inside the clay around each canister the Rotronic humidity and temperature probes are installed.

Analysis of Drilling Mud in Canada

By: Gary Moliver
Rotronic Humidity News - Issue: 1/2002

Newpark Drilling Fluids (Canada) a division of Newpark Resources (USA) is a company operating within North America that supplies water and oil based fluids to the hydrocarbon drilling industry.

Most of the chemicals used in water and oil based fluids are designed to carry out different functions in the course of drilling a well. Some of these tasks include: hole cleaning, i.e. lifting the rock and dirt from the drill bit (bottom of the well) to the surface, penetration through and protection of the rock formations being drilled, providing strength to the rock walls of the hole being drilled, drill string cooling, lubrication, corrosion resistance and buoyancy. Sub-surface pressures are also controlled.

In September 2001 Newpark introduced a new oil-based invert called New-100. An invert is best described as a stable salad dressing; it is water and oil emulsified together in different ratios. (An oil-based invert has a higher percentage of oil (>50%, typically 90%) (external phase), with the water (internal phase) emulsified within the oil).

Oil Inverts are used primarily to add additional protection to water sensitive rock formations, but, the water within the invert has to be modified with salts such as calcium chloride to further reduce the activity of the water phase. The New-100 invert (which can't be titrated) replaces the calcium with a water-soluble liquid. This has two major effects, first it reduces the amount of water in the whole fluid system and secondly it replaces the salt with an environmentally friendly liquid. New-100 is 100% biodegradable and non-bioaccumulative (i.e. no salt build up in drilling wastes disposed of at approved sites).

So how does Rotronic fit into this? The water sensitive shale (rock) can vary in different parts of the world; but within North America the water activity (a_w) ranges from 0.7 – 0.8. The internal phase of an invert is adjusted to be slightly less than the a_w of the rock to prevent water from flowing from the drilling fluid into the rock resulting in borehole stability problems. With the activity less than the surrounding shale's water flows from the rock to the drilling mud. This has the effect of increasing the water content of the drilling fluid.

If drilling with a calcium chloride invert an increase in water concentration was countered with additions of calcium chloride to maintain the desired salt concentration and water activity. With a New-100 internal phase, an increase in water concentration cannot be easily measured by titration of the internal phase. Newpark knows that the concentration is falling but how to quantify it? We solved this problem using the Rotronic water activity system.   An increase in water content should increase the a_w of the entire invert. After preparing a number of inverts with different a_w internal phases, a correlation were made between the whole mud a_w and the amount of water added.

After five months and more than a dozen New –100 wells drilled in Western Canada, the Rotronic water activity analyzer has proven to be an invaluable tool for this type of application.

HygoClip S – When Maximum Precision is Required

By: Christophe Thubert
Rotronic Humidity News - Issue: 1/2002

The Danube International Company, world leader in the cleaning of industrial clothing, has been recognized due to its innovative technology in the area of cleaning, decontamination, drying and pressing of the most diverse textiles. Both hotels and clinics – Danube's main target groups – have to fulfill the most stringent hygiene and safety requirements.

The technology in the machines manufactured and exported by Danube must therefore offer the utmost reliability. Several years ago, in the course of the continuous development of its range of products, the Danube International Company applied for a patent for the fully automated dry pressing of textiles. The cloth is transported by a roller of variable length that is heated to about 100°C over long periods. The first (competitor) humidity and temperature sensor to be tried out produced bad results, showed effects of saturation and had to be exchanged frequently. Then the HygroClip-S from Rotronic was tested over a period of nine months – with success!

The HygroClip S in combination with an MOK-02-XX cable ensures reliable humidity measurement, even in long term operation. The sensor's resistance to saturation, its longevity, and the long-term stable precision of its measurements has contributed significantly to this success. The exchangeability that the HygroClip S technology permits is much valued by users with regard to the ease of machine maintenance. In addition, each HygroClip S is calibrated and supplied with temperature compensation, which has the advantage that it can be exchanged without alternations having to be made to the machine controls.

What Does Humidity Have to Do with Deep Space Missions?

Rotronic Humidity News - Issue: 1/2003

<u>The European Deep Space Antenna Project in New Norcia (Western Australia)</u>

The European Space Agency operates and maintains a network of ground stations, which consists of several stations using 15m antennas in the short wave band for telemetry, command and tracking in support of spacecraft operations. A 35m Deep Space Ground Station at New Norcia (Western Australia) now augments this network, and was ready for operational use as of autumn 2002.

The facilities feature three (3) Rotronic HygroFlex 2 temperature and humidity transmitters which transmit climatic humidity and temperature data, via an RS-232 interface, directly to the European Space Operations Centre (ESOC) in Darmstadt (Germany). Sensors are mounted within Rotronic VHTS2 ventilated radiation shields on a collapsible aerial mast, with the HygroFlex transmitters installed in an enclosure underneath, and are powered by a solar panel and battery. The weather data is used to improve the directional accuracy required for deep space missions especially in the X-Band (ca.8Ghz). Directional errors caused by, for example, weather dependent atmospheric refraction that can be corrected by the refraction model. The refraction index is a function of temperature, humidity, atmospheric pressure and antenna elevation. The antenna is calibrated using stars as signal sources and positional references, provided there is no wind load on the mechanical structure. Wind speed information is used to disable the correction process when certain speeds are exceeded.

The New Norcia antenna is one of the largest in the world used for Telemetry, Tracking and Command (TT&C) applications and represents the jewel in the network of ground stations operated by the ESOC. This exceptional antenna is required for high performance communications with deep space and high elliptical orbit missions, in particular for the European Space Agencies (ESA) science missions Rosetta and Mars express. Reliable long distance communications between the New Norcia ground station and the Rosetta spacecraft are essential to acquire scientific data collected by the instruments on board the spacecraft. It also allows the operations centre to remotely control the spacecraft and its instruments over distances of up to 900 million kilometers away from Earth, more than six times the distance from Earth to the sun. As with all other ESA ground stations the New Norcia antenna will be remotely controlled and operated from ESOC at Darmstadt.

The ESA is planning to enlarge the network by a second antenna of the same size in Europe. This represents a further step in the enhancement of the European Deep Space network in the Ka band, and is core to the future of the Aurora project.

Rotronic Sensors in the Brick Industry

By: Rainer Hofmann
Rotronic Humidity News - 1/2003

The history of brick manufacturers can be traced back to at least the 3rd millennium BC. We know that the ancient Egyptians used bricks when building the Temples of Karnak, and the Romans were prolific in their use. Today, the brick industry has to deal with the challenge of manufacturing a quality brick in immense quantities. This means that the manufacturing process is becoming more and more automated, and that better and better process control is required. In parallel, reduction in energy consumption is a high priority. Before the bricks are fired, they are placed in a drying chamber for about 44 hours where the moisture is extracted.

The company Olfry has been producing bricks and tiles in all their possible forms for the last one hundred years. For the last 15 years they have been using Rotronic humidity and temperature transmitters to control the drying process. The benefits of humidity control are clear; bricks which are fired with too much moisture within their structure crack or explode. If the brick is over dried, unnecessary amounts of energy is expended.

The exact measurement of humidity in the brick and tile industry has often created a problem: As the brick enter the drying chambers with a very high moisture content, condensations often forms on the surfaces of the drying chamber, and more significantly, on the measurement probe. This causes corrosion of metals including the connections of the humidity and temperature sensors. Depending on the levels of condensation formed, and the control strategy, the life of the sensors could be anything from a few weeks to a few years. When sensors fail, they of course, have to be replaced. This could prove costly for the customer. Perhaps more significantly, incorrect measurements cause failures of the process control, leading to higher scrap rates and less profit for the brick manufacturer. It is clear that other solutions have been sought, but at that time there was simply no alternative.

Solution: By working closely with the company Olfry, Rotronic has made a start in tackling the problem. Whenever the relative humidity is above 85%RH, the sensors are heated. As soon as the humidity falls below this threshold, the heating is switched off and the measurement is performed in the usual way. Thanks to this technology, the condensation of water vapor is avoided and the life time of the sensors has been multiplied. The new probes have been in use for the last two years. According to the acting Deputy Manager, Mr. Viefhues, “They have functioned correctly for the past two years without causing us any problems. This has led to us replacing the existing probes with the new type. It has completely solved our problems”.

Humidity Absorption from Munters with Rotronic Humidity Instruments

By: Joseph Farcher
Rotronic Humidity News - 1/2003

Munters is a company renowned throughout the world for air dehumidifying systems. The new Munters Ice Dry system for cold rooms and refrigerated storage has been tested and is available for sales in the USA and England. It is now available across Europe. It dehumidified the air that penetrates into cold areas, especially through open doors and conveyor belt openings. The dry air eliminates the risk of accidents caused by slippery ice, and significantly reduces the need for deicing. This system will also improve working conditions in a cool room; dry floors, less humidity in the air and the elimination of icing improves safety and profitability. Munters cooperates with Rotronic in many countries. For example the bridge over the Oresund between Sweden and Denmark was furnished with dehumidifying systems from Munters. The humidity measuring instruments were naturally from Rotronic. Munters (Switzerland) AG puts Rotronic transmitters before all others. Josef Facher, project manager of Munters (Switzerland) AG explains: We use Rotronic instruments for all process-controlled installations because they have a superior standard of quality. The humidity sensors are extremely long lasting and accurate. The instruments of the M3 series are capable to calculate psychometric parameters. But what is especially important is the interchangeability of the probes which has reduced our service cost immensely. A Rotronic HygroClip sensor can be exchanged in seconds. Also the transmitter doesn't need to be switched off. A diagnosis or system validation by computer is no problem with the new M series devices thanks to a service interface. It means that there is no downtime. And of course the competitive prices of Rotronic instruments are a convincing argument.

The build-up of the ice in cold rooms and refrigerated warehouses is a well established problem. The humidity in the air condenses and forms ice on countless surfaces, for example, the floor. Every time more humid air enters the room the pockets of ice get larger so that after a certain period of time the room must be defrosted.

The humidity measuring instruments from Rotronic M series are used to control the dehumidifier and make it possible to obtain precise control within narrow margins, and therefore contribute significantly to energy optimization. They can, depending on the application, provide measurement of relative humidity, or psychometric calculations plus the temperature.

The life cycle of machines and facilities is increased when there is less humidity servicing intervals are reduced because of the lower levels of corrosion. Manual cleaning becomes a thing of the past. The advantage of this system will become especially clear in summer and autumn. With IceDry the build up of ice almost completely fails to appear even in summer. The necessity to defrost the plant becomes less and less frequent and cold rooms can be kept dry with the new Ice Dry system from Munters.

Rotronic instruments contribute through their high level of precision and the possibility of performing psychometric calculations to a plant which optimizes energy use and operates at a favorable cost. The dry air prevents the growth of mold and other micro-organism, which is clearly important in cold rooms especially where groceries and other perishable products are stored.

Climate Surveillance in Vienna Palace Liechtenstein

Ernest Aringer
Rotronic Humidity News - 1/2003

The construction of Liechtenstein Palace was completed in 1705. Many famous artists worked on this impressive building designed to be the summer residence of Prince Johann Adam Andreas of Liechtenstein (1657-1712). The art loving prince insisted on the magnificent furnishing of his summer property and commissioned some of the most respected artists of his time.

Use of the Palace over the course of centuries

In the 18th Century the garden palace was used as the summer residence of the Liechtenstein family and to celebrate various festivals. At the beginning of the 19th century Prince Johann Josef of Liechtenstein (1760-1836) decided to concentrate the family's extensive art collection from various palaces and castles at the Liechtenstein Palace. It remained there between 1944 and 1948, when it was moved to Vaduz as a result of the war. The building, including the ceiling works, were subject to a basic restoration in 1978/79.

The collection of the Prince of Liechtenstein will return to the Danube metropolis in early 2004. One of the largest collections of Rubens, important works of Van Dyck, Lucas Cranach and Rafael are just as wonderful as those of Rembrandt, van Ruysdael and Hamilton.

Climate Control

It is clear that all of these works of art are extremely valuable and correspondingly must be protected, preserved and stored correctly. Control of the climate surrounding the various works is the most important factor. Of course the climate of the exhibition rooms was considered in the course of the renovation. Because the palace is a protected building, conventional air conditioning with ventilation ducts could not be used. Fan coils, which are mounted behind the wood of the sills, were chosen. To control the relative humidity of the exhibition rooms, over 50 Rotronic transmitters of the FH series were installed. Thanks to these, the aesthetic demands of the architecture can be fulfilled. The transmitters have been mounted next to the hidden fan coils. The HygroClip S probes were sunk into the wall by special flanges so that only the probe tips are visible. The connecting cables run under the plaster to the measuring sensor.

An important factor in the purchasing decision was the simple interchangeability of the HygroClip sensor, which is of great importance for such applications. Since the installation is concealed, it is especially important that the probes can be easily replaced without particular expense. A welcome side effect is that service costs are also reduced in this way. Rotronic has miniature sensors for use in museums of 4mm and 5mm diameter respectively which can be installed practically anywhere and are virtually invisible.

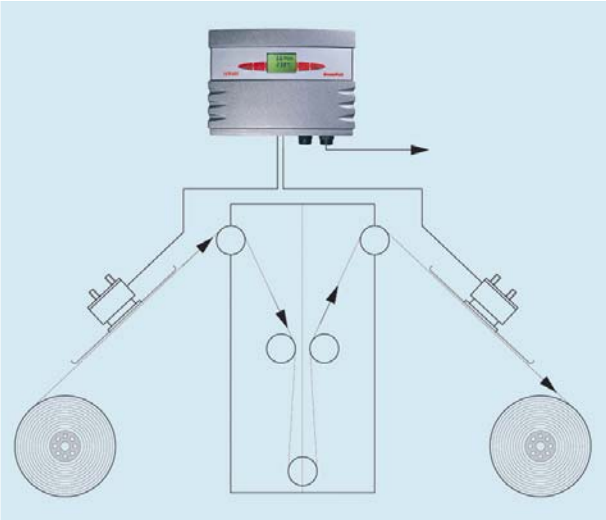
Humidity Measurement on the Moving Paper Web

By: Roland Scheurich
Rotronic Humidity News - 1/2003

Bayropa Jung GmbH, situated in Wertingen, Germany, celebrated its 25th anniversary in the year 2000. The paper tiger, as Bayropa is known, not only have extensive printing experience, but also possesses state of the art roll-offset printing machinery with paper-widths up to 100cm and DIN A4 production lines for pre-printed laser paper with a throughput of 6600 sheets per minute. Of course, Bayropa is also using state of the art technology for their humidity measurement.

Humidity is a very important parameter in the paper and printing industry. Humidity influences the characteristics of a printing process, especially in high volume laser printers. When the paper humidity is not correct, the paper tends to curl, and hence is unacceptable to customers.

Problem: Statistical data alone is not enough to maintain high quality. Paper manufacturers only provide average humidity values for paper webs of more than 10m in width. Therefore, single paper rolls may be well out of tolerance. This is the result of the paper production process, which delivers paper webs of 10 m width that are cut into smaller webs only at the end of the manufacturing process.



The solution is online measurement of equilibrium relative humidity (ERH) and temperature on the web running at 500m per minute. It serves to detect and reject rolls that are out of tolerance.

The online measurement at Bayropa Jung is achieved with one Rotronic BFC-DIO web probe at the machine, with the measurement data managed with HygroFlex transmitters. On-line measurement offers the following advantages:

- Uninterrupted measurement of ERH and temperature on the moving web, and hence the possibility to control the process.
- Avoidance of finish problems by customers.
- Simple logging of the measurement values with validated Rotronic HW3 windows software.
- Alarm function when exceeding threshold values.

A consistent and defined humidity is of great importance when paper is being printed in order to achieve good printing results.

The measurement principle grants a practical and low priced measurement of equilibrium humidity and temperature on the moving paper web.

Web Probe BFC-DIO

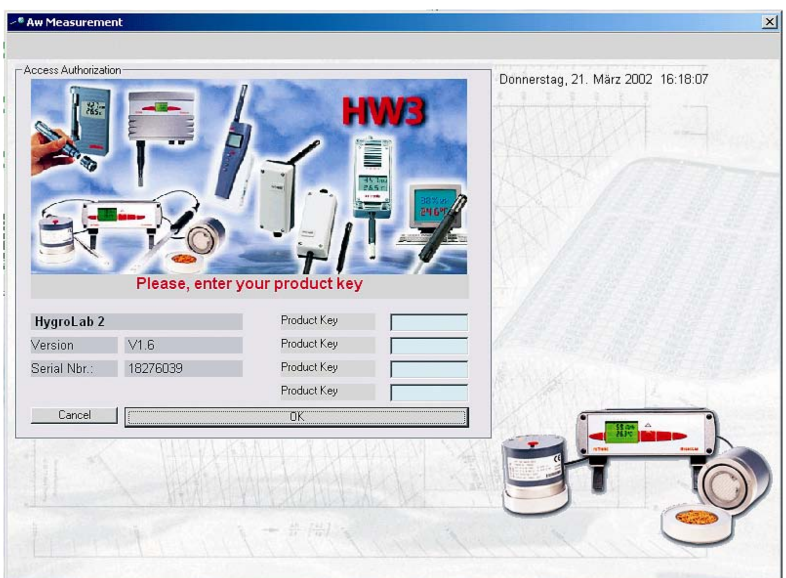
The web probe BFC-DIO is installed directly under or above the moving web, but without direct contact. The humidity and temperature of the paper creates a microclimate in the confined space in and around the measurement chamber that is directly measured. With this simple and well-priced instrument, paper quality can be monitored without interruption, and important conclusions can be made in order to increase the productivity and profitability.

Testing Water Activity in Seeds Helps the Brazilian Rainforest

By: Niek Jan Bink,
Rotronic Humidity News - Issue: 1/2004

Jose Marcio Faria, from Brazi,l is doing a PhD thesis in the Netherlands on storage protocols for seed drying. In this research water activity plays a major role. His supervisor, Dr. Henk Hilhorst, saw the water activity measurement system of Rotronic for the first time with colleagues in the USA. There he became convinced of the capabilities of the Rotronic HygroLab system. He insisted on having one himself, and now they are using it enthusiastically in this project on desiccation sensitivity in legume seeds. Both Dr. Hilhorst and Jose are very satisfied with the Rotronic system. Jose hopes to finish his dissertation next year.

Riparian forests are those that grow along side rivers and they are tightly associated with water, helping in the maintenance of water quality and quantity. In Brazil, these forests belong to the most threatened ecosystems, mainly because of agriculture, grazing and flooding due to formation of lakes for hydroelectric power generation. In a world where the decreased of water supply is of great concern, the importance of the ecological restoration of such kind of forest becomes even more evident. In Brazil, several programs of reforestation with native species have been carried out, attempting to diminish the problem, and seeds are, in practice, the basis of these programs. Thus the importance of storing in seed banks for use in the future to restore these damaged or destroyed environments is obvious.



One of the main tree species used in ecological restoration of riparian forests in south eastern Brazil is Inga vera (Leguminosae), whose seedlings can withstand up to 3 months of total submersion. Its seeds are shed with high moisture content (MC) around 60% (fresh weight basis) and they are recalcitrant, i.e. they die if dried to MCs low enough to allow storage. Fresh Inga vera seeds attain 100% of germination, but upon desiccation they quickly lose viability. If MC drops to 30% they cannot germinate anymore (Faria et al., 2002). Intolerance to desiccations is a serious problem with regard to the long term storage of seeds of this species, as well as other recalcitrant species.

The main objective of this study is to better understand what causes the death of the seeds during drying. This is the first step towards the development of storage protocols for seeds of this species and other recalcitrant seeds.

Traditionally, most of the work on seed desiccation deals with water in seed by assessing only MC, but as shown by Vertucci and Roos (1990) and others water activity (a_w) of seeds provides a much better measure of their physiological level since it relates to the energy status of the water, i.e. the availability of the water to participate in chemical and physical processes. Thus in these studies a_w is measured as it is a much more relevant parameter than MC to assess when desiccation damages start to appear. Another advantage of working with a_w is the possibility of comparing different species, since a number of physiological processes that are relevant to desiccation tolerance or damage have been shown to occur within a narrow range of a_w values (Sun 2002). Moreover, determining the a_w in single seeds or populations is essentially non-destructive. This is a great advantage when dealing with rare species of which only small numbers of seeds are available.

Engine Testing at SAAB

By: Martin Slatis
Rotronic Humidity News - 1/2004

Saab Automobile Powertrain AB is a part of Fiat-GM Powertrain, working on the development and testing of the highly advanced engines used within the Saab range. At its engine test facility in Trollhattan, Sweden, Rotronic HygroFlex Industrial transmitters are used to measure the test conditions.

Engine Power Test

Engines are mounted in test cells where the power output is measured. Engine power is influenced by environmental conditions, so to make sure that the power output is correctly stated, the dew point and temperature of the engine's inlet air is measured. Testing is supervised by an external accredited company, such as TNO in the Netherlands, or AVL from Austria.

Emissions Testing

Car exhaust emissions must be tested to according to different test cycles for different markets. Examples include the FTP75 (FTP-Federal Test Procedure) for the US market, and EUDC (Extra Urban Driving Cycle) for the European market. Cars are run on a dynamometer simulating highway conditions, and the environment is controlled to maintain air temperatures of 20…30°C and dew points of 10…15°C using humidification systems. Humidity measurement transmitters are part of the control system which maintains the correct throughout the testing cycles.

Rotronic Transmitters

Saab recently selected Rotronic HygroFlex transmitters with HygroCLip IM-1 probes to replace another manufacturer's equipment.

The HygroFlex was chosen because of Rotronic reputation for measurement accuracy and long term stability in industrial applications. Another advantage of this instrument is the interchangeable probe which could be calibrated in Saab's calibration facility where a Thunder Scientific two-pressure generator is used. This means that the probes can be quickly and easily removed and calibrated whenever required and to meet validation requirements.

As the test specifications define the humidity in units of dew point, the HygroFlex HTM32D unit was specified. This unit has three analogue outputs which can be freely configured to give %RH, dew point and temperature signals simultaneously.

New Ventilated Radiation Shields Co-Developed with MeteoSwiss

By: Leonhard Low
Rotronic Humidity News - 1/2004

The measurement of climatic humidity and temperature for environmental research, weather forecasting and pollution control is essential. Improvements in the precision and reliability of measurement data will continue to be in demand, especially as our knowledge of the climate and our need to forecast its behavior continues to grow.

Rotronic meteorological probes have been one of the mainstays of climatic humidity measurement for over 20 years. In all applications their precision and long-term stability are well respected. Of course it is the case that in some circumstances even the best equipment doesn't always provide the results that the user needs.In these situations it is essential that further development work is carried out to improve the product. An example of this is the recent development of a new series of ventilated radiation shields to improve measurement performance in some of the harshest conditions.

The new RS ventilated shield has been developed in close cooperation with the Swiss National Meteorological Service (Meteoswiss). It is a highly advanced product, designed to minimize the influence of thermal radiation on humidity and temperature measurements, while maximizing protection from the very worst weather conditions, including horizontally driving wind and rain. The performance of the RS shield in combination with the latest Rotronic meteorological probes is such that in comparative test, measurement performance was practically identical to chilled mirror condensation hygrometers which are used by many National Meteorological Organizations as a reference.

Ventilation of measurement sensors is not a new concept, but it is worth mentioning why this may be useful feature. At high %RH values or saturation, measurement becomes difficult. Small changes or differences in temperature can cause large changes in actual or measured relative humidity. The thermal mass of the humidity probe and its mounting hardware is quite large, and as a result its response to temperature change is slow and condensation may form as a result. This doesn't present a problem for Rotronic probes, as they recover well from periods of saturation, but for a period of time, maximum %RH values may be measured by the probe and the data recorded incorrect. In situations where the condensation takes many hours to evaporate, this can mean incorrect measurements are given for a significant period of time. By actively ventilating the measurement sensors, the measurement part of the installation will return to actual %RH more rapidly.

Ventilation can also be useful where ambient temperatures are higher. The effects of solar gain are minimized by careful shield design and specialist paints, but in combination with active ventilation; measurement performance can certainly be superior to naturally ventilated designs.

The new shields are detailed in our new catalog together with the full range of compatible Meteorological probes.

How Rotronic Helps in the Production of Fine Cheese

By: Thomas Ryan
Rotronic Humidity News - 1/2004

The Courlaoux Cheese Dairy has been part of the Unicopa group since 1996. Unicopa is a large organization with over 5000 employees active in a diverse range of high quality food activities such as poultry, pork butcheries, saltings, as well as dairy products such as cheese from the Jura Courlaoux. Under the management of Messieurs Bouchet and Duchaux, the plant managers/directors, the Jura Courlaoux transforms 17 million liters of milk into 1600 tons of cheese! The final product is 90% Comte and the remainder Emmental, sold under the Rippoz brand.

Milk is skimmed on arrival, and then stands for 32 minutes while curds form before being heated to 55°C in 30 minutes. The curd is then extracted, and over the next 24 hours is pressed and formed into the familiar shape. The cheese is put in pre-maturing cellars for two months, and then spend another two to six further week in maturing cellars before being put into final storage.

The conditions during the maturing process play an essential role in the quality and weight of the cheese. The pre-maturing cellars are controlled to 92 - 93 % RH at 10 - 12 °C. It is imperative that the cheese remain within an environment of 85…95% RH to ensure optimal maturation, so control systems using Rotronic humidity and temperature transmitters are used.

For many years the factory has used Rotronic FT transmitters, and recently these have been upgraded to the latest M2 series with HygroClip-S interchangeable probes. Their improved performance provides a better measurement accuracy of ±0.3°C, and an improved IP65 enclosure gives better protection to the electronics in extreme conditions.

Of even more benefit in this application is the flexibility of maintenance options that the M2 series provides. Interchangeable probes and digital technology allow the Jura Courlaoux to carry out a more rigorous maintenance schedule to achieve best possible measurement results, but without increased costs. A HygroPalm 3 handheld instrument is used to carry out calibration checks, and when necessary used to make adjustments at one or multiple points of temperature and humidity.

The HygroPalm 3 handheld instrument/calibrator is also used by Mr..Duchaux to spot check the absolute humidity. This information allows him to make sure that the conditions in each area are comparable. The combination of M2 series and the HygroPalm gives Mr. Duchaux the tools to ensure that humidity control can have the best possible impact on the quality of the cheese.

Protecting Rodin from Japan's Climate and Earthquakes

By: Masaru Kawanishi
Rotronic Humidity News - 1/2004

The National Museum of Western Art (www.nmwa.go.jp) in Tokyo has recently installed a number of Rotronic HygroClip IC05 mini probes for use in the conservation of the Rodins statues Adam and Eve.

Masaru Kawanishi, of Rotronic's distributor in Japan, Shinyei Kaisha worked closely with the staff of the museum to provide a measurement solution which would integrate with very specialized measurement and protection technology used to preserve the Rodin statues. To further complicate the application, the statues were also mounted onto a seismic isolator to protect them from the frequent earthquakes in the region. The complexity of this mounting platform meant that the humidity probes used needed to be of the highest quality and smallest dimension. The 5mm diameter probe and cable of the HygroClip IC05 was therefore ideal.

HygroClip IC05 probes are connected to HygroFlex transmitters, which takes the digital measurement information from the probe, and converts it to an analog signal for NWMA monitoring requirements.

The NWMA curator commented, "The HygroClip IC05 works very well, especially during the summer months when humidity can be very high. Its very small size means it can fit into the limited space inside the statues without a problem. Humidity is very important to the conservation of works of art, especially paintings, and in the future I want to use the HygroClip IC05 to measure between the canvas and backboard."

The HygroClip IC05 is one of a range of different probe types that are available to connect to the HygroFlex. The digital electronics retain the probe calibration data so they can be interchanged without loss of measurement performance.

How Humidity is used in Fuel Cell Research

By: S. Ikawa
Rotronic Humidity News - 1/2005

A fuel cell is a power generating device using materials such as natural gas, methanol, petroleum, coal, gas or biomass.

Since the fuel cell is based on the reverse reaction of electrolysis of water, it does not require the combustion of fuel like typical thermal power generation methods. Therefore, it has attracted considerable attention as a high efficiency power generator with low environmental impact. In addition, since heat is produced by the chemical reaction, the fuel cell can supply both electricity ad heat simultaneously. Fuel cells are intended not only for large scale power plants, but also as a power source for homes, office buildings hospitals, cars and buses etc. The power output can be from tens to tens of thousands of kW.

Why the Dew Point is Measured?

A fuel cell requires high temperature and high dew point values for efficient power generation. When testing fuel cells, monitoring of temperature and dew point is required to determine the best atmosphere for power generation. Usually, dew point is measured at the inlet and outlet of hydrogen rich gas and air circuits. Measurements are generally performed at four points on each testing machine.

The Challenge of Measurement in Fuel Cell Testing

Fuel cell testing machines are operated between 80…150°C and 90…100% relative humidity. The dew point can reach almost 90°C! The atmosphere is demanding for humidity sensors. During testing, the humidity sensors are exposed to extreme conditions, where condensation may easily occur.

Additionally, the sensors must withstand pressure. Fuel cell testing machines supply minute molecular gases like hydrogen. Therefore, it is very important that the probes are pressure tight. The leakage of hydrogen will result in pressure changes, which in turn affect the test results of the fuel cells. Which Instrument is Suitable?

As mentioned above, the atmosphere of the fuel cell testing machine sometimes reaches 150°C. The product of choice is a HygroFlex 3 transmitter with an analog output of the calculated

dew point signal to the control system of the fuel cell testing equipment. The recommended probe is a customized HygroClip IE-X/M screw-in pressure probe with an operating range of -50…200°C. This probe can withstand both high temperature and pressure up to 50 bar. To ensure that the application is successfully measured, it is recommended that the probe is heated to prevent condensation. In case condensation occurs, a special filter has been designed to allow the condensate to flow away. The high tolerance of Rotronic hygromer series to high humidity, high temperature and saturation conditions, means that it is one of the available methods for measurement in this application.

Who are the Customers?

Around the world, car manufacturers, electric power, gas, fuel companies and universities are rushing into the development of fuel cells. Many manufacturers of testing machinery are approaching the fuel cell developers with different testing designs and a variety of measurement requirements. One of Rotronic strengths is our flexibility to customize products exactly to the customer's needs and in this complex and demanding application, we are often specified as the product of choice.

HygroClip Probes and the Quality of Plastic Molding

By: Ernst Aringer
Rotronic Humidity News - 1/2005

For maximum output and reliable quality, injection molding machinery must be constantly cooled. If condensation occurs on the surface of the cooled molds, this affects the quality of both product and molds.

Eisbaer Trockentechnik GmbH in Goetzis (Austria) operates in the building drying and plant construction sector of the plastics industry. They are specialists in air drying systems that are used with injection molding machines, and for film cooling in extrusion plants. The common requirement of these machines is their constant need for very dry air to maintain high standards of quality and productivity. In order to avoid condensation on the molds, the dry air of the DAs-devices (Dry Sir System) is blown into the portioned tool section of the machines in exactly the right volume. To ensure that condensation does not occur, temperature and humidity in the tooling section are constantly measured. This allows adjustment of the dryer performance and optimizes energy consumption.

The second point of humidity measurement is at the process of air outlet of the dryer system. It provides for permanent control of dryer performance which brings additional benefit for the customer in terms of simplified support and maintenance.

The interaction of these two measurements guarantees condensation free tools with minimal energy consumption, and ensures continuously high surface quality of the products with maximum productivity. In combination with a customized version of an M23 duct mount transmitter, the Rotronic HygroClip probes are mounted directly in the output duct of the DAS system and into the tool section of the injection molding machine. The interchangeability of the probes ensures practically uninterrupted operation even during maintenance, whilst the probe key features of accuracy and stability helps to ensure consistent air quality.

<u>Advantages from the Customer's Point of View</u>

The competitiveness in the plastics industry, and especially in the PET industry, is determined by the so called cycle time. This describes the time elapsing from closing the tools, injection of liquid plastic, cooling down and hardening of the molded part, opening of the tools and ejection of the part. The major part of the cycle time is usually taken by cooling and hardening of the molded part. It is therefore obvious that the industry tries to reduce this time to a minimum. Reducing the cycle time can be achieved by cooling the tools (usually with water). In extreme cases the cooling can be close to nearly freezing, and this results in condensation of the humidity from the surrounding air on the tools (by corrosion) and product's surface by water marks.

The Eisbar DAS-System helps prevent this by drying the supply air. Due to a slight overpressure in the tool section, humid ambient air cannot reach the tools section. In short, injection molding is possible with the best possible capacity and quality anywhere in the world, regardless of the actual ambient conditions thanks to Eisbar systems and Rotronic probes.

Further Applications for DAS-Systems:

- Drying of plastic granulate
- Drying of material such as fertilizers
- Food drying in silos, of sweets, dry vegetables
- Corrosion prevention in power stations, military facilities, water works, etc.

Humidity Generators - Examining Uncertainty

David P. Love
VP – Sales & Marketing
Rotronic Instrument Corp
Reprinted with permission from *Pharmaceutical Formulation & Quality* – November 05, 2005

From saturated salt solutions to humidity generators there are many different ways to generate a humidity value for calibration. In order to define a method for your humidity calibrations and also to properly evaluate the number of commercial solutions available on the market today, there are several key areas requiring close examination. In order to simplify the discussion this article will broadly review the issues presented when using a commercial humidity generator. These are available from a variety of manufacturers. The principles used to generate the precise humidity environment vary; two pressure generators, two temperature generators, and split flow are the most common. Within each group the instruments may appear similar; there are however vast differences in the accuracy and quality of the instruments available in each category. The critical question is how to tell the difference between a good and a poor instrument. Are the lower cost generators really as good as the more expensive generators? This brief review will provide a framework for facilitating the decision process required to decide which humidity generator is right for your requirements.

Let's look initially at the problems associated with the humidity generator itself. In order to properly calibrate a humidity sensor, the reference generator must provide a very stabile and uniform humidity and temperature environment. This is critical for two very basic reasons. First, small temperature gradients throughout the chamber can result in significant errors in the measured relative humidity values. A temperature gradient inside the calibration chamber of as little as ±0.1°C can cause errors of more than ±0.5% RH at higher humidity levels. While temperature differences within the chamber will lead to problems with the humidity level, the design of the instrument can also lead to gradients in the actual humidity in the chamber. Therefore, it is also critical to examine the homogeneity of the humidity values in the chamber. Poor airflow design, the previously mentioned temperature effects, and inefficient chamber design can lead to uneven humidity values.

The second reason a uniform and stabile chamber is critical is the response time of the instrument under test to real changes in humidity and temperature. These instruments move rather slowly in response to environmental changes (primarily due to their physical mass). Therefore if the environment never truly stabilizes, then the instrument will never come to equilibrium with the environment. In this situation, an accurate calibration is close to impossible.

Well, if the stability and uniformity of both humidity and temperature inside the chamber are critical to proper calibration then it also makes sense to review the contribution of the instruments that measure these parameters to the overall uncertainty of the calibration.

When you are serious about the quality of the calibrations you are performing you will want to use reference instruments separate from the humidity generator control instruments to provide the reference values. This is due to that fact that laboratory grade temperature and RH reference instruments will provide better levels of uncertainty than the control instruments used on most if not all humidity generators.

On the temperature side, a high quality reference PRT co-located with the instruments under test will help minimize any errors. The manufacturer of the temperature reference should provide you with all of the uncertainty data needed to calculate the uncertainty of your calibrations. To maintain consistency of your calibrations over time, it is critical that the reference thermometer is always exact same location. If the reference thermometer is not in the same location the changes in the temperature reading may be small; however the focus is to minimize all uncertainties, no matter how small.

Which instrument to use for the reference humidity value is a more confusing choice. There are several different types of methods used as a humidity control instrument: chilled mirrors, pressure and temperature measurements, and capacitive humidity sensor to mention the main types. Which instrument is used to control humidity is less important than which instrument is used as the reference humidity instrument. It is generally accepted that that a reference chilled mirror will provide an excellent level of uncertainty in a humidity calibration. As with the temperature reading, the manufacturer of the chilled mirror should be able to provide you with all the data necessary to calculate the uncertainty of the reference instrument. If the accuracy of your calibrations is a bit looser, say ±2.0% or higher, the use of a high quality RH instrument based on a capacitive sensor can be used. But, it is critical to note here that the sensors should be specialized for calibrations at one point only. This is due to the negative effect sensor hysteresis has on the accuracy of the capacitive sensor.

Chamber stability, chamber uniformity, and reference instruments uncertainty have all been discussed regarding their impact on your instrument choice. But what can be done with all this information? It must be pulled together in a total study of the uncertainty of the calibration system. A summary example of this is shown in Table One. Each column of data has a specific uncertainty analysis which generated the values shown in the table. For example, for the column titled HygroGen, data was developed on the stability and uniformity shown in the HygroGen for both temperature and humidity. This data was then summarized into one standard uncertainty using common statistical methods.

In order to properly evaluate a calibration instrument for use in your calibration lab it is very important to review the data provided by the instrument manufacturer. This information must include specifications addressing the stability and uniformity of the calibration chamber. The specifications must also address both temperature and humidity variables. This data should include analysis at the actual temperatures and humidity values you plan to use. Due to mechanical design, controller performance, temperature control, and the humidification system, performance of the various generators on the market today can vary widely over the stated operating range of the unit.

Look at all the facts, compare the key uncertainty data, address your individual calibration needs, and then decide which instrument is right for your calibration laboratory.

Table One
Uncertainty of % RH inside the Hygrogen (at 20 °C)

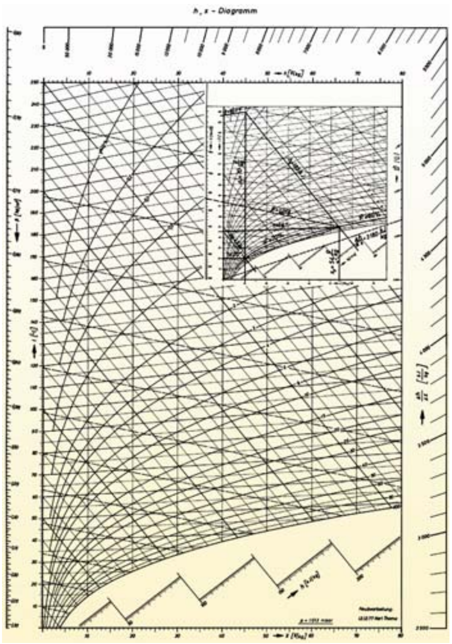
Humidity	**Reference Temperature uncertainty σ % RH**	**Chilled Mirror Uncertainty σ % RH**	**Dew Point to RH conversion algorithm σ %RH**	**HygroGen σ % RH**	**Expanded Uncertainty 95% confidence (k=2) %RH**
80%	0.190	0.367	0.001	0.073	**0.84**
50%	0.107	0.244	0.001	0.125	**0.59**
35%	0.071	0.177	0.002	0.036	**0.39**
10%	0.027	0.088	0.014	0.048	**0.21**
5%	0.017	0.048	0.007	0.044	**0.14**

Instruments included in the chilled mirror uncertainty analysis include the following:

- -Temperature indicator Chub-E4, mod. 1529-R (Hart Scientific)
- -Platinum Resistance Thermometer (PRT), mod. 5614 (Burns Engineering)
- -Dew point indicator, mod. M1 (General Eastern)
- -Chilled mirror sensor mod. 1311DR-SR (General Eastern)

The Rotronic document "HygroGen 2 – Stability and Uniformity Analysis" is available at www.rotronic-usa.com for detailed information on the analysis. Modifications reserved.

The development of this data follows ANSI/NCSL Z540-2-1997 (R2002) standard regarding the expression of uncertainty in measurement. Please refer to this standard for a more detailed discussion on uncertainty analysis if needed.



Other Helpful Information

‘

Other Helpful Information

Temperature Conversion Table

To Convert			To Convert			To Convert			To Convert		
ºC	ºF or ºC	ºF	ºC	ºF or ºC	ºF	ºC	ºF or ºC	ºF	ºC	ºF or ºC	ºF
-45.56	-50	-58.0	-16.11	3	37.4	13.33	56	132.8	42.78	109	228.2
-45.00	-49	-56.2	-15.56	4	39.2	13.89	57	134.6	43.33	110	230.0
-44.44	-48	-54.4	-15.00	5	41.0	14.44	58	136.4	43.89	111	231.8
-43.89	-47	-52.6	-14.44	6	42.8	15.00	59	138.2	44.44	112	233.6
-43.33	-46	-50.8	-13.89	7	44.6	15.56	60	140.0	45.00	113	235.4
-42.78	-45	-49.0	-13.33	8	46.4	16.11	61	141.8	45.56	114	237.2
-42.22	-44	-47.2	-12.78	9	48.2	16.67	62	143.6	46.11	115	239.0
-41.67	-43	-45.4	-12.22	10	50.0	17.22	63	145.4	46.67	116	240.8
-41.11	-42	-43.6	-11.67	11	51.8	17.78	64	147.2	47.22	117	242.6
-40.56	-41	-41.8	-11.11	12	53.6	18.33	65	149.0	47.78	118	244.4
-40.00	-40	-40.0	-10.56	13	55.4	18.89	66	150.8	48.33	119	246.2
-39.44	-39	-38.2	-10.00	14	57.2	19.44	67	152.6	48.89	120	248.0
-38.89	-38	-36.4	-9.44	15	59.0	20.00	68	154.4	49.44	121	249.8
-38.33	-37	-34.6	-8.89	16	60.8	20.56	69	156.2	50.00	122	251.6
-37.78	-36	-32.8	-8.33	17	62.6	21.11	70	158.0	50.56	123	253.4
-37.22	-35	-31.0	-7.78	18	64.4	21.67	71	159.8	51.11	124	255.2
-36.67	-34	-29.2	-7.22	19	66.2	22.22	72	161.6	51.67	125	257.0
-36.11	-33	-27.4	-6.67	20	68.0	22.78	73	163.4	52.22	126	258.8
-35.56	-32	-25.6	-6.11	21	69.8	23.33	74	165.2	52.78	127	260.6
-35.00	-31	-23.8	-5.56	22	71.6	23.89	75	167.0	53.33	128	262.4
-34.44	-30	-22.0	-5.00	23	73.4	24.44	76	168.8	53.89	129	264.2
-33.89	-29	-20.2	-4.44	24	75.2	25.00	77	170.6	54.44	130	266.0
-33.33	-28	-18.4	-3.89	25	77.0	25.56	78	172.4	55.00	131	267.8
-32.78	-27	-16.6	-3.33	26	78.8	26.11	79	174.2	55.56	132	269.6
-32.22	-26	-14.8	-2.78	27	80.6	26.67	80	176.0	56.11	133	271.4
-31.67	-25	-13.0	-2.22	28	82.4	27.22	81	177.8	56.67	134	273.2
-31.11	-24	-11.2	-1.67	29	84.2	27.78	82	179.6	57.22	135	275.0
-30.56	-23	-9.4	-1.11	30	86.0	28.33	83	181.4	57.78	136	276.8
-30.00	-22	-7.6	-0.56	31	87.8	28.89	84	183.2	58.33	137	278.6
-29.44	-21	-5.8	0.00	32	89.6	29.44	85	185.0	58.89	138	280.4
-28.89	-20	-4.0	0.56	33	91.4	30.00	86	186.8	59.44	139	282.2
-28.33	-19	-2.2	1.11	34	93.2	30.56	87	188.6	60.00	140	284.0
-27.78	-18	-0.4	1.67	35	95.0	31.11	88	190.4	60.56	141	285.8
-27.22	-17	1.4	2.22	36	96.8	31.67	89	192.2	61.11	142	287.6
-26.67	-16	3.2	2.78	37	98.6	32.22	90	194.0	61.67	143	289.4
-26.11	-15	5.0	3.33	38	100.4	32.78	91	195.8	62.22	144	291.2
-25.56	-14	6.8	3.89	39	102.2	33.33	92	197.6	62.78	145	293.0
-25.00	-13	8.6	4.44	40	104.0	33.89	93	199.4	63.33	146	294.8
-24.44	-12	10.4	5.00	41	105.8	34.44	94	201.2	63.89	147	296.6
-23.89	-11	12.2	5.56	42	107.6	35.00	95	203.0	64.44	148	298.4
-23.33	-10	14.0	6.11	43	109.4	35.56	96	204.8	65.00	149	300.2
-22.78	-9	15.8	6.67	44	111.2	36.11	97	206.6	65.56	150	302.0
-22.22	-8	17.6	7.22	45	113.0	36.67	98	208.4	66.11	151	303.8
-21.67	-7	19.4	7.78	46	114.8	37.22	99	210.2	66.67	152	305.6
-21.11	-6	21.2	8.33	47	116.6	37.78	100	212.0	67.22	153	307.4
-20.56	-5	23.0	8.89	48	118.4	38.33	101	213.8	67.78	154	309.2
-20.00	-4	24.8	9.44	49	120.2	38.89	102	215.6	68.33	155	311.0
-19.44	-3	26.6	10.00	50	122.0	39.44	103	217.4	68.89	156	312.8
-18.89	-2	28.4	10.56	51	123.8	40.00	104	219.2	69.44	157	314.6
-18.33	-1	30.2	11.11	52	125.6	40.56	105	221.0	70.00	158	316.4
-17.78	0	32.0	11.67	53	127.4	41.11	106	222.8	70.56	159	318.2
-17.22	1	33.8	12.22	54	129.2	41.67	107	224.6	71.11	160	320.0
-16.67	2	35.6	12.78	55	131.0	42.22	108	226.4	71.67	161	321.8

Glossary

Accuracy – The nearness of agreement between a measured value and a known standard.

Calibration – The comparison of an instrument's performance to a known standard. Can be used to verify an instrument's accuracy or used to adjust the accuracy of an instrument through a given set of instructions.

Capacitive Humidity Sensor – A sensor consisting of a hygroscopic dielectric material placed between a pair of electrodes forming a small capacitor.

Condensation – The change in phase of a gas to a liquid state.

Dew Point – The temperature to which a gas must be cooled in order for condensation to form.

Frost Point – The temperature at which frost forms upon cooling a gas.

Linearity – The variation between a know standard and the instrument's reading across the low and high end of the measuring range.

Mixing Ratio – The mass of water vapor within an area divided by the mass of dry air within the same area.

Repeatability – The closeness between multiple readings performed under the same test conditions.

Resolution – The smallest change in a reading that an instrument is capable of displaying. Typically governed by the instrument's display.

Response Time – How long an instrument takes to react to changes in a given condition.

Traceability –The property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons, all having stated uncertainties.

Uncertainty of Measurement – Any measurement, has components which effect results given. These can include systematic (instrument) and random (human) errors. The combined amount of these errors form the uncertainty of measurement.

Water Activity – The relative humidity reached in a sealed container where a hygroscopic product has been placed. Water activity (a_w) is expressed on a scale of 0 to 1.

rotronic instrument corp

160 East Main Street
Huntington, NY 11743
Phone +1-631-427-3898
Fax +1+631-427-3902
www.rotronic-usa.com

rotronic messgeräte gmbh

Einsteinstrasse 17 – 23
D-76275 Ettlingen
Phone +49-7243-383 250
Fax +49-7243-383 260
www.rotronic.de

rotronic ag
TECHNIK FÜR PROFIS

Grindelstrasse 6
CH-8303 Bassersdorf
Phone +41-44-838 11 11
Fax +41-44-837 00 73
www.rotronic.com

rotronic sarl

56, Bld. de Courcerin
F-77183 Croissy Beaubourg
Phone +33-1-60 95 07 10
Fax +33-1-60 17 12 56
www.rotronic.fr

rotronic instruments uk ltd

Unit 1 A, Crompton Fields
Crawley,West Sussex RH10 9EE
Phone +44-1293-57 10 00
Fax +44-1293-57 10 08