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MEASUREMENT AND CONTROL

The measurement of humidity in air

Introduction

Besides temperature, humidity is a very important process parameter. The relative humidity of the surrounding atmosphere, for example, has a far-reaching influence on our well-being and our health.

In industrial processes the correct adjustment of humidity is often decisive for the competitiveness and quality of the product. Correct adjustment of humidity level can also contribute to appreciable savings in energy consumption.

The list of applications in which the measurement of humidity is considered important can be extended indefinitely. Wherever the water vapour content of the air can produce or influence chemical, physical or biological processes it is very important to ensure that humidity is monitored continuously.

Concepts and physical laws

The composition of air

Clean and dry air contains the following constituents (in vol %):

78.10 % nitrogen
20.93 % oxygen
0.93 % argon
0.03 % carbon dioxide
0.01 % hydrogen

together with smaller amounts of neon, helium, krypton and xenon.

In addition to these constituents, indoor and outdoor air contains a number of gases and solids as well as a certain quantity of moisture in the form of water vapour. Air is therefore a homogeneous mixture of different gases and can be considered as an "ideal gas". Solar radiation and wind ensure uniform mixing of the gases involved so that there is no stratification despite the differences in specific gravity.

Dalton's Law P = P1 + P2 + ...

The total pressure of a gas mixture consists of the sum of the partial pressures of its constituents. Expressed in simple terms, air thus consists of dry air and water vapour.

$$P = P_W + P_{dry}$$

where P_w represents the partial pressure produced by water vapour and P_{dry} the sum of the partial pressures of all other gases.

Saturation water vapour pressure

Air is capable of absorbing and storing a certain quantity of water vapour depending on its temperature. This quantity increases with increasing temperature.

At any particular temperature the resulting water vapour pressure can only rise up to the saturation limit which is designated as the saturation water vapour pressure P_S.

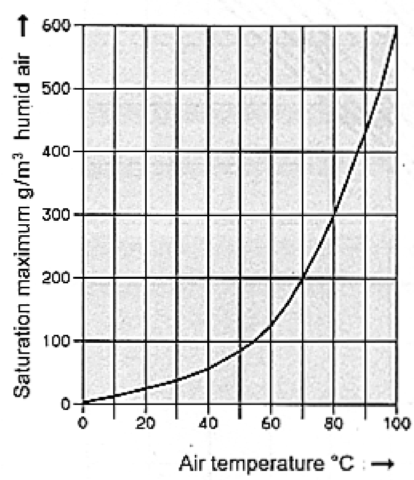

Fig. 1: The water vapour pressure curve indicates the saturation maximum of water vapour content in air at different temperatures

The atmospheric pressure and the presence of other gases or contaminants have no influence on the behaviour described above.

Dew point

The dew point temperature T_d is the temperature at which air is saturated with water vapour; further addition of water vapour or cooling of the air results in condensation. The excess water vapour condenses as rain, mist or condensate. The saturated state is maintained. The dew point temperature is equal to the water vapour saturation temperature and can be a maximum of 100 °C at normal pressure.

Measured parameters

The humidity content of air can be characterised by two parameters. We distinguish between relative humidity and absolute humidity.

Relative humidity

Relative humidity is defined as the ratio between the actual partial vapour pressure P_W in a gas and the maximum possible vapour pressure, i.e. the saturation vapour pressure P_S, at the particular temperature.

$$rH = \frac{P_W}{P_S\,(t)} \cdot 100 \quad [\%]$$

Relative humidity is a non-dimensional value. It represents a ratio and is specified in percent.

Since the saturation pressure depends only on the temperature of the air, it follows that relative humidity is also dependent on temperature. Relative humidity decreases with increasing temperature, and vice versa.

The influence of temperature variations on relative humidity can be very appreciable.

	10 °C	20 °C	30 °C	50 °C	70 °C
10 %rH	±0.7 %	±0.6 %	±0.6 %	±0.5 %	±0.5 %
50 %rH	±3.5 %	±3.2 %	±3.0 %	±2.6 %	±2.3 %
90 %rH	±6.3 %	±5.7 %	±5.4 %	±4.6 %	±4.1 %

Table 1: Influence of a temperature variation of ±1 °C at different temperatures and humidities

Absolute humidity

Absolute humidity a is the quantity of water vapour contained in a certain volume of air.

$$a = \frac{\text{mass of water vapour}}{\text{volume of air}}$$

The unit for absolute humidity is g/m³. Measurement of absolute humidity has the great advantage that it represents the quantity of water actually present in a gas, for example, independent of temperature.

Mixing ratio or water content (x)

This parameter indicates the ratio of the mass of water vapour to the mass of the dry gas. Commonly used units are g/kg dry air and %.

It specifies how many grammes of water vapour are contained in a kg of dry air. The determination of water content plays an important role in processing technology, since such data provide more valuable information than relative humidity.

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There is a fixed relationship between the values of absolute and relative humidity, see Fig. 2.

The unit of absolute humidity can be selected to suit individual requirements.

The most common units are:
- dew point temperature °C
- mixture ratio g/kg dry air
- absolute humidity g/m³

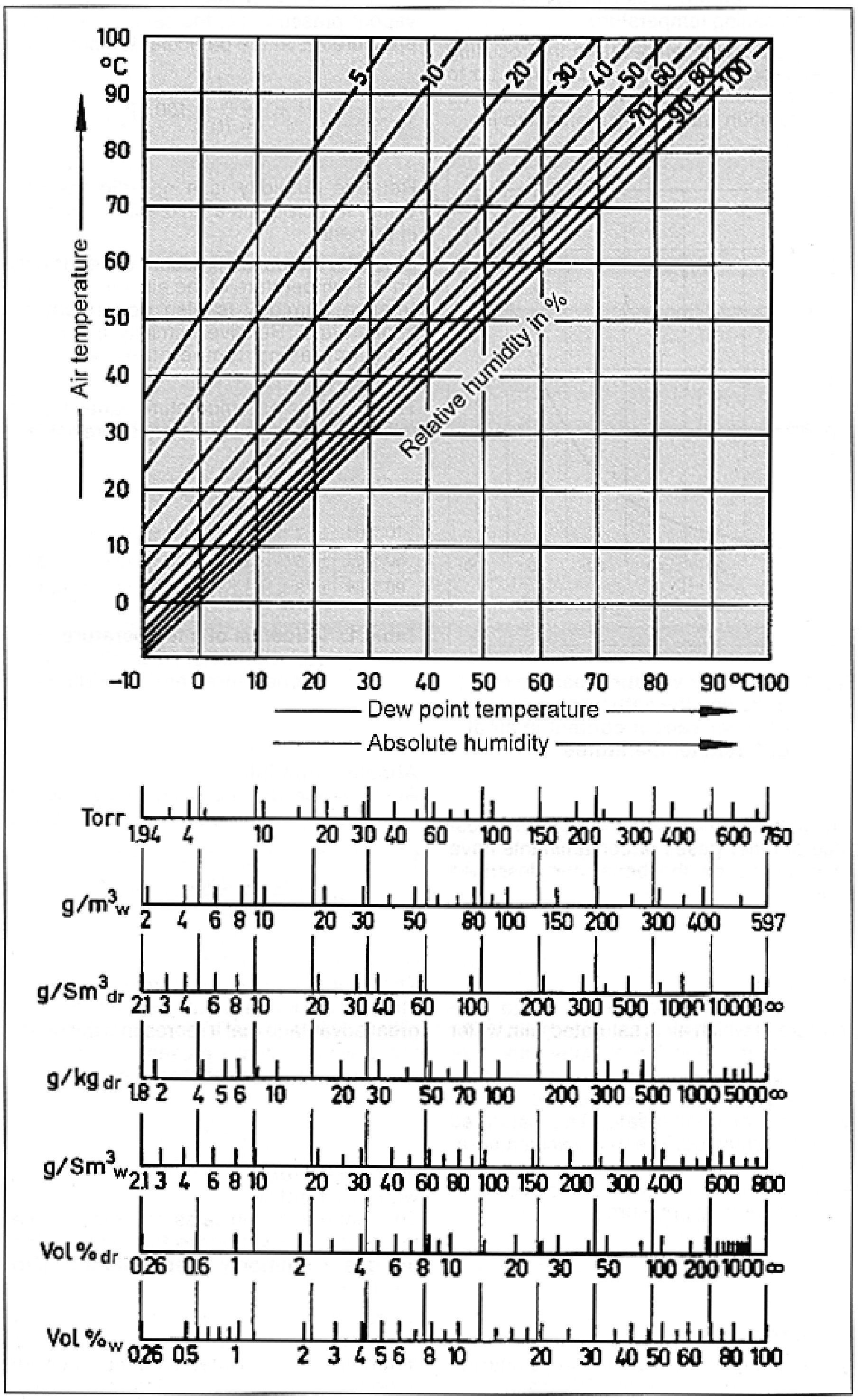

Fig. 2: Units of absolute humidity and their relation to relative humidity

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Relationship between temperature, moisture content and relative humidity

These relationships are shown in the i-x diagram (Mollier diagram, see Fig. 3).

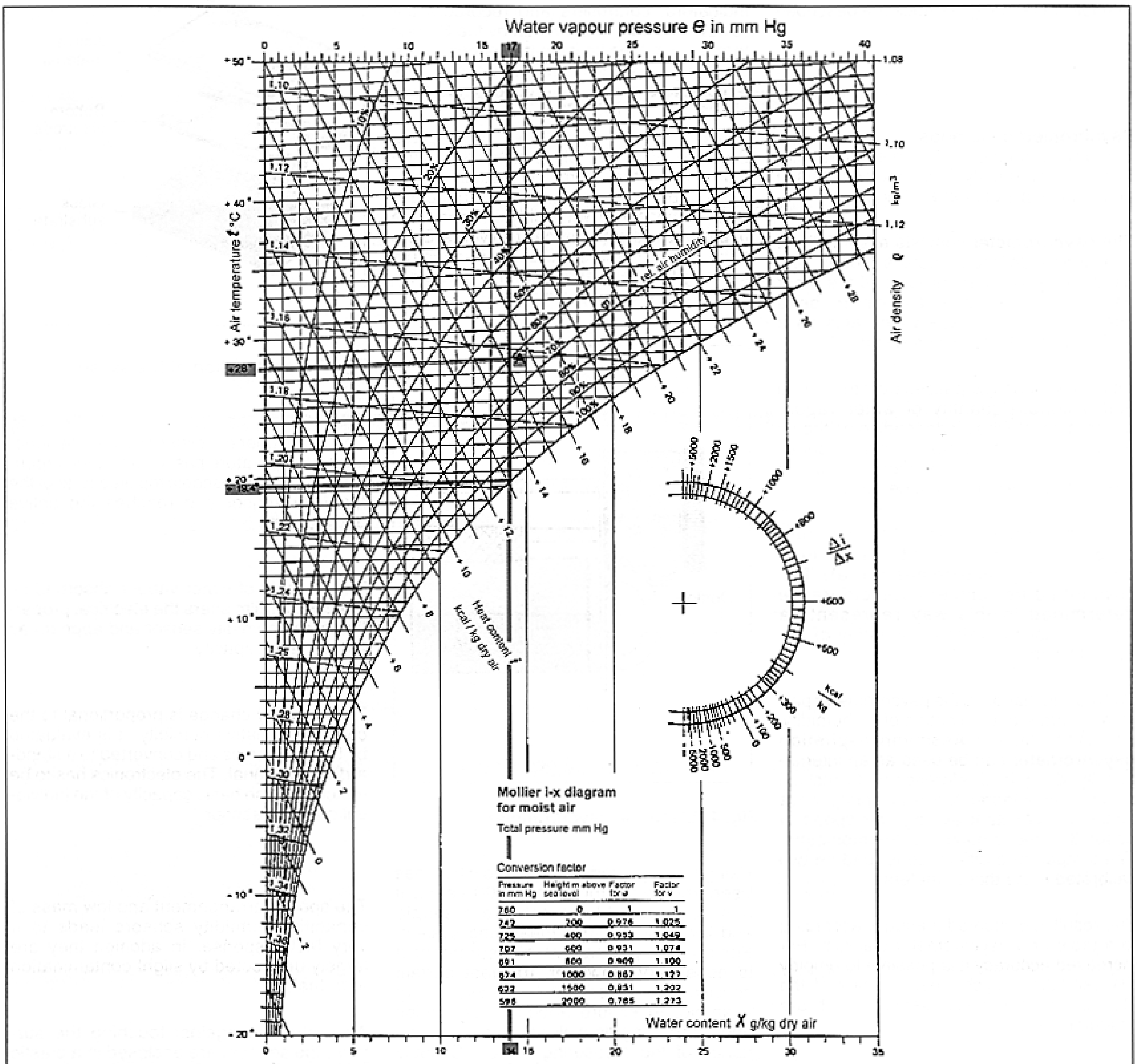
Example for the use of the diagram:

a) Determining the water content x and the water vapour pressure e
Measured values: air temperature 28 °C
air humidity 60 % rH

Look up the measured values in the diagram and determine the point of intersection A. From this intersection draw a vertical line and extend it to the top and bottom edges of the diagram. The intersection with the top scale gives the water vapour pressure e = 17 mm Hg, at the bottom scale the water content x = 14 g/kg.

b) Evaluating the dew point temperature
Measured values: air temperature 28 °C
air humidity 60 % rH

Find the point of intersection A as under a). From the intersection A go down vertically to the maximum humidity line 100 % and from that point draw a horizontal line to the left-hand scale with the temperature graduation. The new intersection gives the required dew point temperature of 19.4 °C.



Pressure in mm Hg	Height m above sea level	Factor for ρ	Factor for v
760	0	1	1
742	200	0.976	1.025
725	400	0.953	1.049
707	600	0.931	1.074
691	800	0.909	1.100
674	1000	0.887	1.127
632	1500	0.831	1.202
596	2000	0.785	1.273

Fig. 3: Relationship between temperature, moisture content and relative humidity

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Humidity measurement methods and their application

A number of different methods are used for measuring humidity in air. The choice of the most suitable method is usually made by the user based on the local situation. The use of a simple but correctly applied humidity measuring device often permits achieving a better accuracy or meeting the particular requirements.

In order to provide general assistance, some of the best known and widely used humidity measuring methods are described below.

Psychrometric methods

The psychrometric method measures relative humidity directly. This method is based on the principle of heat exchange.

The **psychrometer** consists essentially of two independent temperature probes, one used as the wet bulb probe and the other as the dry bulb probe. The wet probe is surrounded by a tissue which acts as a wick and is saturated with water.

An air flow has to be passed over this probe and a certain quantity of water vapour evaporates into the air depending on the air temperature and humidity. This produces a cooling effect at the surface of the wet thermometer (wet bulb temperature).

At the same time a second temperature probe measures the ambient air temperature (dry bulb temperature). The psychrometric temperature difference determined in this way represents a measure for the relative humidity of the surrounding air.

With careful handling the psychrometer permits accurate determination of air humidity. For example, the **Assmann aspiration psychrometer** can be used as an internationally recognised reference and checking device. An integral fan with spring drive ensures a constant average air speed of about 3 m/sec around the thermometers. The temperature difference is read on two calibrated glass thermometers.

The result is evaluated manually according to a table or a psychrometer diagram. For increased accuracy it is possible to employ the aspiration psychrometer tables of the German meteorological service which are graduated in 0.1 °C.

In addition to the aspiration psychrometer there are numerous different arrangements.

The field of application of most mechanical psychrometers with glass thermometers is restricted to the climatic range for temperatures up to 60 °C. The advantage of this type of instrument is that no electrical supply is required.

Electrical psychrometers have more extensive applications. Here the wet bulb and dry bulb temperatures are measured using Pt 100 resistance thermometers.

In the case of microprocessor-controlled indicators, controllers and recorders the relative humidity determined by the Sprung formula can then be indicated or processed directly, using a suitable input circuit. The temperature range covered extends from almost 0 °C to 100 °C.

Because of its reliable construction compared with other humidity measuring devices, the psychrometric method generally permits measurement in dirty and corrosive gases and in the presence of solvents. Electrical psychrometers are used for example for long-term measurement in meat processing and cheese production.

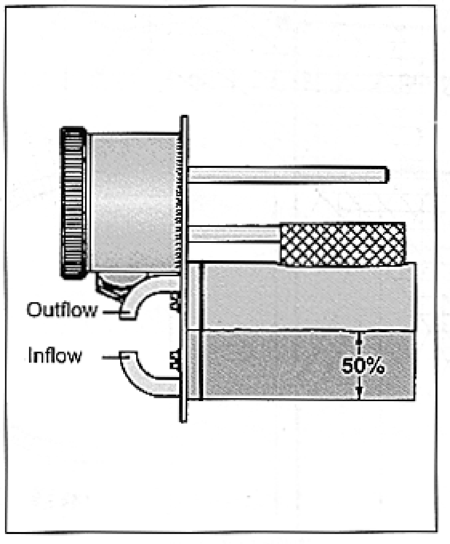

Fig. 4: Electrical psychrometer

Using the psychrometric method which has been known for more than 100 years, it has been possible to achieve a simple and low-cost humidity measuring system. For reliable permanent measurement it is necessary, however, to meet certain specific user criteria. It is necessary, for example, to ensure adequate ventilation and moistening as well as proper maintenance of the measuring device. Suitable details are contained in the operating instructions and method descriptions of the individual instruments.

Capacitive method

The capacitive method is based generally on the condenser principle. The function of the humidity sensor depends on the change of capacity of a thin polymer film through the absorption or removal of water molecules.

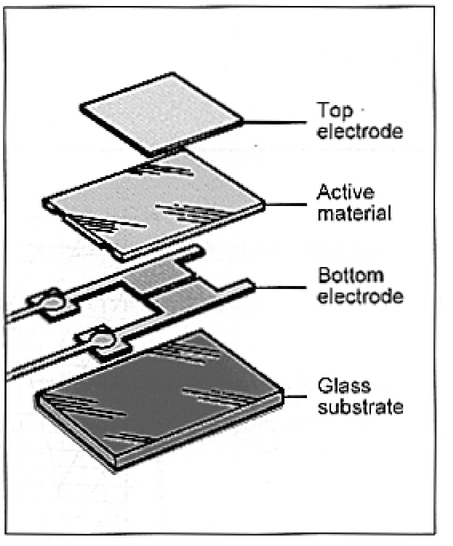

Fig. 5: Construction of the sensor

The atmospheric moisture content depending on temperature passes as water vapour through the hygroscopic top electrode of the humidity sensor and reaches the active polymer film.

The quantity of water vapour absorbed by the polymer film alters the electrical properties of the humidity sensor and appears as a change in capacity.

This capacity change is proportional to the change in relative humidity; it is evaluated by the electronics and converted to a standard output signal. The electronics has to be matched to the basic capacity of the individual humidity sensor.

The special arrangement and low mass of capacitive humidity sensors leads to a very fast response. In addition they are largely unaffected by slight contamination and dust.

As protection against touching the surface, the sensors are enclosed in a plastic housing. Condensation-free versions are available for use in the higher moisture range.

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Capacitive measurement methods are used e.g in climatic engineering and in industrial processes where there are no high concentrations of corrosive gases or solvents.

The standard measuring range of capacitive humidity sensors is generally from 10 — 90 % rH. High-grade versions permit use in the full range between 0 and 100 % rH.

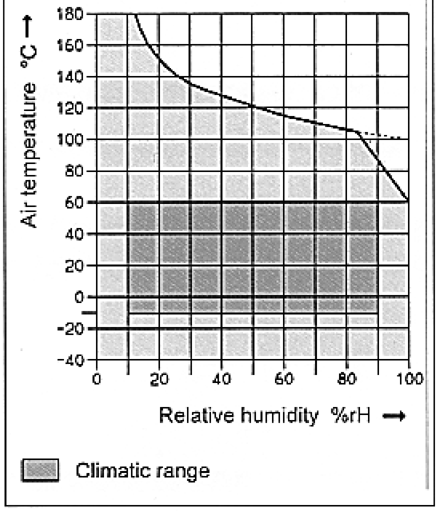

Fig. 6: Working range of a capacitive humidity sensor for industrial applications

One of the main advantages of the capacitive method is the temperature range over which humidity can be measured.

For example, modern industrial humidity transducers permit measurements between −40 and +180 °C, with the temperature being measured simultaneously and provided as a standardised output signal.

Variations of the working range shown are possible depending on the instrument version.

Because of its purely electrical measurement the capacitive method offers a further advantage. High-performance humidity transducers incorporating modern microprocessor technology can be provided with a large number of possible options and functions.

Variations in gas pressure and air flow rates have hardly any influence on the capacitive humidity sensor so that instrument versions are available for measurement under pressures between 0 and 100 bar.

Accuracy is between ±2 and ±5 % rH depending on the instrument version. Under certain conditions it is even possible to achieve accuracies of ±1 % rH.

Hygrometric methods
The hygrometric procedure employs the special characteristics of hygroscopic fibrous materials for determining humidity. If these fibres are exposed to ambient air, there is (after an equilibration period) a measurable change in length depending on the moisture content of the air.

From the condition of the fibres it is possible to deduce the amount of humidity present.

Hygrometric measuring elements employ mainly specially prepared plastic threads and human hair.

Hair measuring element
The action of the measuring element is based on the fact that the hair used is capable of absorbing moisture. This moisture take-up causes the hair to swell which shows itself mainly in a change in length.

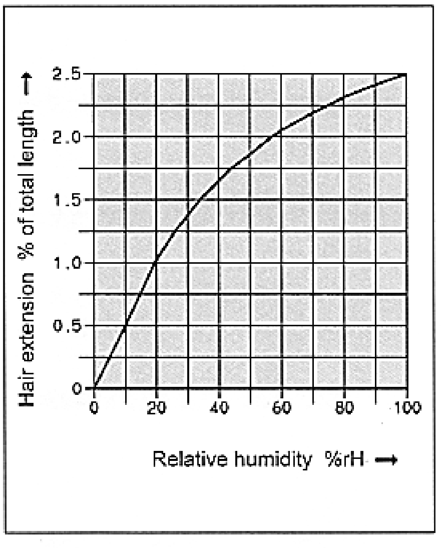

Fig. 7: Change of hair length depending on relative humidity

Increasing humidity in the air causes an increase in the hair length. The length change amounts to approx. 2.5 % of the total hair length for a humidity change from 0 to 100 %. At high humidities the hair exhibits only a relatively small increase in length (see Fig. 7).

Hair measuring elements are used mainly in dial instruments in the climatic field. A special precision mechanism converts the length change of the hair into a pointer or pen movement. For increased mechanical strength it is usual to combine several hairs into a hair bundle or hair grid.

The method offers an accuracy of ±3 % within the range 0 — 90 (100) % rH. Ambient temperatures between −35 and +50 °C can be covered.

When used for longer periods in the low humidity range below 40 % rH the hair element has to be regenerated. This operation consists of exposing the hair hygrometer for approx. 60 minutes to virtually saturated air (about 94 — 98 %). Any correction of the pointer position which may prove necessary can then be carried out using an adjusting screw.

Hair hygrometers are sensitive to hygroscopic dust and have to be suitably protected and/or cleaned at appropriate intervals.

Plastic measuring element
Plastic elements employ plastic threads in place of human hair. A special process is used to give these fibres certain hygroscopic properties. Changes in relative humidity produce a proportional length change of the measuring element. The change in length is again transmitted by a precision mechanism.

Plastic elements offer the advantage that they can be used at higher temperatures (up to 110 °C) and also for longer periods at low relative humidities. No regeneration as in the case of hair element is required here.

The plastic measuring element is resistant to water and unaffected by dry dirt, dust, loose fibres and similar contamination. The measurement/working range covers (0) 30 — 100 % rH, but depends on ambient temperature (see Fig. 8).

Accuracy is ±2 — 3 %.

Hygrometric instruments with a plastic element are employed for long-term humidity measurement in industrial processes and in climatic engineering because of their extensive stability and compatibility with higher temperatures.

Various instrument versions are available to suit particular applications.

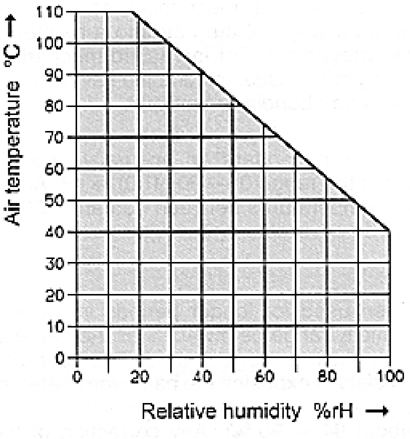

Fig. 8: Maximum temperature and humidity of a plastic measuring element

They include, among others:

Hygro transducers
In these devices the length change of the plastic element is sensed through a suitable system and usually converted into a linear resistance signal. Versions are also available with built-in 2-wire transmitter so that standardised current and voltage signals are provided at the output. Units with an additional temperature measuring range are referred to as hygro-thermo transducers.

Hygrostats
In this variant the length change of the measuring element is used to operate a switching contact. Hygrostats are used to control humidifiers and de-humidifiers.

Hygrograph
A hygrograph is a humidity recorder with a hygrometric hair or plastic sensing element. Additional temperature recording is also possible (hygro-thermograph). Applications include meteorological stations.

Hygrometric methods can be used generally for humidity measurement at atmospheric pressure and in a non-aggressive atmosphere.

Use in corrosive atmospheres or those containing solvents should be avoided as these result in incorrect readings depending on type and concentration, and can even destroy the measuring element.

Conclusions

The section on humidity measurement methods and their applications covers basic principles. Actual instrument descriptions and technical data may therefore vary for different manufacturers. Full information can be obtained from operating instructions or data sheets for the individual instruments.