

# Humidity —

## Part 3: Guide to the measurement of humidity

ICS 13.040.01

|                           |
|---------------------------|
| Confirmed<br>January 2011 |
|---------------------------|

# Committees responsible for this British Standard

The preparation of this British Standard was entrusted to Technical Committee CPI/29, Humidity and temperature conditioning requirements, upon which the following bodies were represented:

Institute of Measurement and Control

Institute of Printing

Institute of Chemical Engineers

SIRA Limited

Society of Environmental Engineers

National Physical Laboratory

British Compressed Gases Association

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 2 June 2004

© BSI 2008  
© Crown Copyright 2004.  
Reproduced by permission of the Controller of HMSO.

The following BSI references relate to the work on this British Standard:  
Committee reference CPI/29  
Draft for comment 03/305320 DC

ISBN 978 0 580 63055 2

## Amendments/corrigenda issued since publication

| Amd. No. | Date        | Comments                                    |
|----------|-------------|---------------------------------------------|
| C1       | 30 May 2008 | “–” changed to “+” in equations (3) and (4) |
|          |             |                                             |
|          |             |                                             |
|          |             |                                             |

# Contents

|                                                                                                                                                         | Page               |
|---------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| Committees responsible                                                                                                                                  | Inside front cover |
| Foreword                                                                                                                                                | ii                 |
| 1 Scope                                                                                                                                                 | 1                  |
| 2 Normative references                                                                                                                                  | 1                  |
| 3 Terms and definitions                                                                                                                                 | 1                  |
| 4 Basic concepts of humidity                                                                                                                            | 1                  |
| 5 Significance of temperature and pressure for humidity measurement                                                                                     | 11                 |
| 6 Introduction to methods for measuring humidity                                                                                                        | 11                 |
| 7 Selection of a type of hygrometer                                                                                                                     | 16                 |
| 8 Recommended practices in humidity measurement                                                                                                         | 19                 |
| 9 Performance and calibration                                                                                                                           | 22                 |
| Annex A (informative) Examples of the effects of temperature and pressure on humidity measurement                                                       | 28                 |
| Bibliography                                                                                                                                            | 31                 |
| Table 1 — Alternative humidity terms                                                                                                                    | 3                  |
| Table 2 — Interconversion formulae for air–water system, to three significant figures                                                                   | 7                  |
| Table 3 — Antoine equation coefficients for air–water system                                                                                            | 8                  |
| Table 4 — Calculation methods for various humidity parameters                                                                                           | 10                 |
| Table 5 — Summary of some of the features of the main types of humidity measurement                                                                     | 15                 |
| Table 6 — Equilibrium relative humidities generated over saturated solutions of a selection of salts                                                    | 25                 |
| Table A.1 — Approximate effect of a temperature change of $\pm 1$ °C on relative humidity at various existing temperatures and relative humidity levels | 29                 |

## Foreword

This British Standard was prepared by Technical Committee CPI/29.

This British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

**Compliance with a British Standard cannot confer immunity from legal obligations.**

### Summary of pages

This document consists of a front cover, an inside front cover, pages i and ii, pages 1 to 35 and a back cover.

The BSI copyright notice displayed in this document indicates when the document was last issued.

## 1 Scope

This British Standard gives guidance on the selection and use of instruments for the measurement of humidity. It introduces the main concepts and practical techniques involved in measuring humidity in air and other “inert” gases and provides an explanation of how to make valid and meaningful measurements. It also includes guidance on specifying or choosing appropriate equipment for a known application.

## 2 Normative references

The following normative documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 1339-1, *Humidity — Part 1: Terms, definitions and formulae*.

BS 1339-2, *Humidity — Part 2: Humidity tables*.

## 3 Terms and definitions

For the purposes of this part of BS 1339, the terms and definitions given in BS 1339-1 apply.

## 4 Basic concepts of humidity

### 4.1 General

The word “humidity” denotes the presence of water or another vapour in air or other gas. Water vapour is the gaseous form of water, and can be thought of much like any other kind of gas. It is normally transparent, and makes up about one percent of the air around us. Hence, by far the most common application of humidity is the air–water vapour system. However, the concept is equally applicable to water vapour or any other vapour in any gas, e.g. a solvent vapour being dried from a pharmaceutical in a nitrogen atmosphere. Previous British Standards have concentrated entirely on the air–water system, as have the equivalent ASHRAE (American Society of Heating, Refrigeration and Air conditioning Engineers) standards. This new part of BS 1339 is the first to attempt a generalized statement suitable for all vapour–gas systems.

The term “vapour” usually applies to a gas which is below its critical temperature and can therefore become liquid if the pressure is increased, or if the vapour concentration in the gas becomes too high. In contrast, virtually all the components of air are above their critical temperature and will not liquefy under any normal conditions; air is therefore known as a permanent gas. In this Guide, where the word “gas” appears hereafter, it should be taken to mean a permanent gas.

### 4.2 Importance and relevance of humidity

The presence or absence of water vapour in air or other gas influences a vast range of physical, chemical and biological processes. Humidity measurements are important for a wide range of industries and, to some, they are a critical aspect of business costs, product quality, and health and safety. For example, they are used in air conditioning, meteorology, horticulture, food processing, solids drying and general chemical engineering.

There are many different techniques for measuring humidity and the subject is complicated by the confusing variety of ways of expressing humidity.

Humidity is a relatively difficult quantity to measure in practice, and the accuracy achievable is not as good as for many other areas of measurement. For example, the mass of objects can be found in a typical laboratory by weighing to within one part in 100 000. Similarly, atmospheric pressures can often be measured to within five parts in 10 000. Humidity, however, can commonly be measured to only about three parts in 100, i.e. with an uncertainty in the result of  $\pm 3$  % of value.

To make a reliable humidity measurement at any given level of accuracy, it is necessary to use an appropriate measuring technique in a sound way. To do so, one should be able to define the measurement task, select a suitable method of measurement underpinned by a reliable calibration, carry out the measurement correctly without introducing errors, and interpret the result of the measurement. This Guide is intended to assist you in this process.

### 4.3 Scientific fundamentals

Humidity arises in practice because, in the same way that hot water gives off steam, so water at lower temperatures – including ice – also gives off water vapour. Wherever there is water or ice, there is evaporation (and its opposite, condensation). The extent to which this happens depends upon a number of factors, the most important of which is temperature. Similarly, other liquid or solid materials – most of which have some water – will give off (or sometimes absorb or adsorb) water vapour. Water vapour can also be found in places where there is no liquid or solid nearby, for example in remote parts of the Earth's atmosphere. Likewise, where any other liquid is present, its vapour will also be present in the surroundings to some extent, depending on the volatility of the liquid.

Air (or empty space, or any other gas) has a given capacity to hold water vapour. This capacity depends mainly on temperature. Generally speaking, the hotter the air, the more water vapour it can hold. At any particular temperature, air that contains its full capacity of water vapour is said to be “saturated”. The “relative humidity” of the air expresses how fully saturated it is with water vapour. A variety of other (“absolute”) measures are used to express how much mass of water vapour is actually present (irrespective of temperature or level of saturation). These include mole fraction, mixing ratio and volumetric humidity. The same principles can be applied to any vapour held in any gas, but the capacity to hold vapour depends on the identity of the vapour and, to a lesser extent, the gas.

If unsaturated air is cooled without changing the mass of water vapour present (i.e. at constant mole fraction or mixing ratio) it will reach a temperature at which it is saturated, and liquid water will then appear as condensation; this temperature is the “dew point”. Below 0 °C, the water will tend to appear as ice, and this is known as the “frost point”.

If water is allowed to evaporate into unsaturated air, the air will cool down and the mass of water present in the gas will also increase. It will again reach saturation, but at a higher temperature and mass fraction than the dew point temperature. Under ideal conditions with no heat losses, the final temperature is known as the “adiabatic saturation temperature”. It is closely related to the “wet bulb temperature”, which is the temperature reached by a liquid surface in contact with a flowing gas – see 4.7.

### 4.4 Alternative humidity terminology

Table 1 summarizes the terms and formulae used in BS 1339 and compares them with other terminology in widespread use. For detailed definitions of these terms and expressions of the formulae, refer to BS 1339-1.

Table 1 — Alternative humidity terms

| BS 1339 term                                                                            | ASHRAE (1997) term                 | Alternative terms and synonyms                              | BS 1339 symbol | Units (SI)         | Formula                 |
|-----------------------------------------------------------------------------------------|------------------------------------|-------------------------------------------------------------|----------------|--------------------|-------------------------|
| Volumetric humidity                                                                     | Absolute humidity                  | Water-vapour density, vapour concentration                  | $d_v$          | kg/m <sup>3</sup>  | $d_v = m_v/V$           |
| Mixing ratio                                                                            | Humidity ratio                     | Absolute humidity, mass ratio, moisture content (dry basis) | $Y$            | kg/kg              | $Y = m_v/m_g$           |
| Specific humidity                                                                       | Specific humidity                  | Wet-basis humidity                                          | $Y_W$          | kg/kg              | $Y_W = m_v/(m_g + m_v)$ |
| Mole fraction                                                                           |                                    | Volume fraction <sup>a</sup>                                | $y$            | mol/mol            |                         |
| Vapour pressure                                                                         | Vapour pressure                    | Partial pressure                                            | $p$            | Pa                 |                         |
| Total pressure                                                                          | Total pressure                     | Atmospheric pressure                                        | $P$            | Pa                 |                         |
| Saturation vapour pressure                                                              | Water vapour saturation pressure   |                                                             | $p_s$          | Pa                 |                         |
| Saturation mixing ratio                                                                 | Saturation humidity ratio          | Saturation humidity                                         | $Y_s$          | kg/kg              |                         |
| Relative humidity                                                                       | Relative humidity                  |                                                             | $\psi$ , rh    | %, % rh            | $\psi = p/p_s$          |
| Percentage saturation                                                                   | Degree of saturation               | Mass-ratio relative saturation                              | $\mu$          | %                  | $\mu = Y/Y_s$           |
| Adiabatic saturation temperature                                                        | Thermodynamic wet-bulb temperature |                                                             | $t_{as}$       | °C                 |                         |
| Wet-bulb temperature                                                                    | Wet-bulb temperature               |                                                             | $t_{wb}$       | °C                 |                         |
| dew point temperature                                                                   | dew point temperature              |                                                             | $t_{dp}$       | °C                 |                         |
| Frost-point temperature                                                                 | Frost point temperature            | dew point temperature <sup>a</sup>                          | $t_{fp}$       | °C                 |                         |
| Humid volume                                                                            | Specific volume                    |                                                             | $v$            | m <sup>3</sup> /kg | $v = V/m_g$             |
| Volume (of mixture)                                                                     | Volume                             |                                                             | $V$            | m <sup>3</sup>     |                         |
| Gas density                                                                             | Density                            |                                                             | $\rho$         | kg/m <sup>3</sup>  | $\rho = (m_g + m_v)/V$  |
| NOTE Numbers expressed as percentages may also be expressed as dimensionless fractions. |                                    |                                                             |                |                    |                         |
| <sup>a</sup> Term is not an exact equivalent, although commonly used.                   |                                    |                                                             |                |                    |                         |

#### 4.5 Problems of terminology

The widespread use of humidity in a broad range of industries can give rise to problems, as the traditional practices and common terminology often differ between these different industries.

For example, for many applications, it is convenient to state humidity as a volumetric concentration in grams per cubic metre, and this is often called “absolute humidity”. This presents no real problems for conditions close to atmospheric pressure and ambient temperature. However, this expression is totally unsuitable for chemical engineering applications, as temperature will often vary greatly during the drying process, and gas volume varies with it. Instead, it is necessary to use the ratio of mass of vapour to mass of dry gas, and this is also known as absolute humidity in chemical engineering applications. The use of the same term for two quantities which are not even dimensionally equivalent can create confusion, and BS 1339-1 recommends that the term “volumetric humidity” is used for the first form (concentration) and that “mixing ratio” is used for the second form (mass ratio). However, it should be recognized that the term “absolute humidity”, in both forms, is deeply entrenched in industry and is unlikely to be eliminated in the foreseeable future.

Below the normal freezing point of a liquid, vapour normally condenses out as ice, and the temperature at which this occurs is the frost-point temperature. However, under certain circumstances, the vapour can appear as supercooled liquid. This occurs at the supercooled liquid dew point temperature, which is slightly lower than the frost-point. For example, the difference is about 1 °C for water vapour at –10 °C, and about 4 °C at –50 °C. The term “dew point” is often used in a general way to refer to the scale encompassing both dew point and frost-point temperatures. Below 0 °C, the term “frost-point” is used to specifically indicate ice. To refer specifically to the liquid form below the normal freezing point, the term “supercooled” is used, e.g. supercooled water dew point.

Another quantity causing confusion is the equilibrium relative humidity (ERH), or water activity, of a substance. This is a property of the substance itself, and denotes the relative humidity of a vapour–gas mixture in equilibrium with the substance at its given composition (including liquid moisture content). Hygroscopic materials have low ERH values, tending to absorb water vapour from the air unless the latter is very dry. The ERH should not be confused with the relative humidity itself, which is a property of the vapour–gas mixture.

#### 4.6 Invariant and variable parameters

It is useful to note the parameters of a vapour–gas mixture that do not vary with pressure and (dry-bulb) temperature for a given composition. These tend to be based on mass or the amount of substance (moles) rather than volume. They include:

- mixing ratio and specific humidity;
- mole fraction (or volume fraction of gases or vapours);
- molecular weight;
- mass or mass flowrate.

A near-fundamental quantity is the pure saturation vapour pressure, which is a function only of temperature. It is linked to the actual saturation vapour pressure in a gas mixture by the enhancement factor, which is a function of total pressure, but the correction is generally less than 0.5 % at atmospheric pressure.

Derived quantities, which tend to vary with temperature, pressure or composition, include:

- volumetric humidity;
- adiabatic saturation temperature and wet bulb temperature;
- gas density and specific (humid) volume;
- saturation vapour pressure in a gas mixture;
- partial pressure of the vapour in an unsaturated gas mixture;
- relative humidity.

#### 4.7 Systems other than air–water

Some common assumptions for the air–water system do not apply to other solvent–gas systems. In particular, the wet-bulb temperature is not identical to the so-called thermodynamic wet-bulb temperature (correctly entitled the adiabatic saturation temperature). The adiabatic saturation temperature is based on an enthalpy balance (i.e. equilibrium conditions) and is easy to calculate but difficult to measure; the wet-bulb temperature is based on heat and mass transfer rates (i.e. kinetically controlled) and is difficult to calculate but easily measured. For the air–water system, they are coincidentally and conveniently almost equal (well within 1 °C at near-ambient temperatures). Hence, calculation equations and measurements for one quantity can be used to give approximate values for the other. However, for other solvents, they can be markedly different, and more rigorous forms of calculation are needed.

#### 4.8 Units used in the formulae

##### 4.8.1 General

The formulae in BS 1339 parts 1 and 2 (and the accompanying program) are generally in SI units. These do not always coincide with standard engineering practice and some common pitfalls are noted in 4.8.2 to 4.8.5. The most frequent problem is confusion between true SI and common engineering units, leading to an error by a factor of 1 000.

##### 4.8.2 Molal mass (molecular weight)

In the original metric system, these were quoted as  $\text{g}\cdot\text{mol}^{-1}$ , so that, for example, the molal mass of water was approximately 18 and that of dry air about 29. When the SI unit of mass was changed to the kg, the unit for “amount of substance” was somewhat illogically left as the mole (gram molecular weight). Hence one mole of carbon-12 contains 12 g of carbon, or 0.012 kg. As a result, molal masses of air and water, quoted in strict SI units, become 0.029 and 0.018 respectively. For engineering purposes, it is often more convenient to use the kilomole (kmol; 1 kmol of C-12 contains 12 kg of carbon) but unfortunately this is not a recognized base SI unit. The formulae in BS 1339-1 use molal mass in  $\text{kg}\cdot\text{mol}^{-1}$ .

##### 4.8.3 Universal gas constant $R$

This is quoted in molal units and is approximately  $8.314 \text{ J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$ . In the formula for vapour pressure, if pressure is quoted in pascals and molecular weights in  $\text{kg}\cdot\text{mol}^{-1}$ ,  $R$  is as given above. If molecular weights are quoted as  $\text{kg}\cdot\text{kmol}^{-1}$  or  $\text{g}\cdot\text{mol}^{-1}$ , the value required in the formula will be  $8\,314 \text{ J}\cdot\text{kmol}^{-1}\cdot\text{K}^{-1}$ .

##### 4.8.4 Specific heat capacity $C_p$ , humid heat $C_s$ and enthalpy $h$ .

The SI unit for heat is the joule, and this gives the specific heat for dry air as being just over  $1\,000 \text{ J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$ , and the enthalpy of dry air at 20 °C on this basis will be about  $20\,000 \text{ J}\cdot\text{kg}^{-1}$ , while the latent heat of evaporation of water is  $2\,500\,000 \text{ J}\cdot\text{kg}^{-1}$ . For engineering purposes, the kilojoule (kJ) is a more convenient unit. All specific heat capacities and enthalpies (including latent heat) should be quoted in the same energy units. For the formulae in BS 1339, kilojoules are used, so that the specific heat for dry air is about  $1 \text{ kJ}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$ , the enthalpy of dry air at 20 °C is about  $20 \text{ kJ}\cdot\text{kg}^{-1}$ , and the latent heat of evaporation of water at 0 °C is  $2\,500.8 \text{ kJ}\cdot\text{kg}^{-1}$ .

When handling engineering data, care should be taken to check whether energies are quoted in joules, kilojoules or calories. If calories are quoted, they may be based on the quantity of heat required to raise the temperature of 1 g or 1 kg of water by 1 °C; the latter unit is more properly termed the kilocalorie. Likewise, enthalpies and specific heats may be quoted per unit mass or per mole, and it is important to check whether grams, kilograms, moles or kilomoles are the base unit.

#### 4.8.5 *Mixing ratio $Y$ and specific humidity $Y_W$ .*

The mixing ratio is the mass of vapour divided by the mass of dry gas; specific humidity is the mass of vapour divided by the mass of moist gas. The SI unit, and the practice in the formulae, is to quote  $Y$  and  $Y_W$  in  $\text{kg}\cdot\text{kg}^{-1}$ , so that typical values for ambient air are about 0.002 to 0.02. However, it is common to see figures quoted in  $\text{g}\cdot\text{kg}^{-1}$ , so that ambient humidities would be in the range 2 to 20.

### 4.9 Main humidity parameters and their calculation

#### 4.9.1 *Mixing ratios, mass and mole fractions*

The mixing ratio  $Y$ , mole ratio  $z$ , mole fraction  $y$  and specific humidity  $Y_W$  are all absolute, invariant values for a gas–vapour mixture of a given composition, as explained in 4.6; they do not change with applied temperature or pressure. They are linked to each other directly. The formulae for converting between  $Y$  and  $Y_W$ , or between  $y$  and  $z$ , are the same for any combination of vapour and gas. However, the identity of the vapour and gas affects the interconversion between mass and mole units, which depends on their molecular weights (molal masses). The complete set of interconversion formulae for the air–water system is given in Table 2 (from 3.2.18 of part 1, which gives the corresponding formulae for other vapour–gas systems).

#### 4.9.2 *Vapour pressure $p$ and relative humidity $\psi$*

The partial pressure of vapour in a gas–vapour mixture,  $p'$ , is linked directly to the mole fraction  $y$  by the total applied pressure  $P$ ; it does not vary with temperature. Again, this makes conversion to other mass- and mole-based invariant humidity terms easy, as shown in Table 2.

The relative humidity  $\psi$  (%rh) is the ratio of the partial pressure to the saturation vapour pressure  $p_s$  (described below); it thus expresses, as a percentage, how close the mixture is to saturation. It varies with temperature and pressure as well as composition.

The distinction between pure vapour pressure  $p$  and actual vapour pressure  $p'$  is explained in 4.9.3.

Table 2 — Interconversion formulae for air–water system, to three significant figures

| Convert to:                                             | $Y$ (or ppm <sub>w</sub> ) <sup>a</sup>         | $z$ (or ppm <sub>v</sub> ) <sup>a</sup>     | $Y_w$                                                 | $y$                                | $p'$                                 | $d_v$                                          |
|---------------------------------------------------------|-------------------------------------------------|---------------------------------------------|-------------------------------------------------------|------------------------------------|--------------------------------------|------------------------------------------------|
| Convert from:                                           |                                                 |                                             |                                                       |                                    |                                      |                                                |
| Mixing ratio <sup>a</sup><br>$Y$ (kg·kg <sup>-1</sup> ) | 1                                               | $z = 1.6078Y$                               | $Y_w = \frac{Y}{1+Y}$                                 | $y = \frac{Y}{(0.622+Y)}$          | $p' = \frac{PY}{(0.622+Y)}$          | $d_v = \frac{0.002167PY}{(0.622+Y)T}$          |
| Mole ratio <sup>a</sup><br>$z$ (mol·mol <sup>-1</sup> ) | $Y = 0.622 z$                                   | 1                                           | $Y_w = \frac{z}{1.6078+z}$                            | $y = \frac{z}{1+z}$                | $p' = \frac{z}{1+z} P$               | $d_v = \frac{0.002167zP}{(1+z)T}$              |
| Specific humidity<br>$Y_w$ (kg·kg <sup>-1</sup> )       | $Y = \frac{Y_w}{1-Y_w}$                         | $z = \frac{1.6078Y_w}{(1-Y_w)}$             | 1                                                     | $y = \frac{Y_w}{(0.622+0.378Y_w)}$ | $p' = \frac{PY_w}{(0.622+0.378Y_w)}$ | $d_v = \frac{0.002167PY_w}{(0.622+0.378Y_w)T}$ |
| Mole fraction<br>$y$ (mol·mol <sup>-1</sup> )           | $Y = \frac{0.622Y}{(1-Y)}$                      | $z = \frac{y}{1-y}$                         | $Y_w = \frac{0.622y}{1-0.378y}$                       | 1                                  | $p' = yP$                            | $d_v = \frac{0.002167yP}{T}$                   |
| Vapour pressure $p'$ (Pa)                               | $Y = \frac{0.622p'}{(P-p')}$                    | $z = \frac{p'}{(P-p')}$                     | $Y_w = \frac{0.622p'}{P-0.378p'}$                     | $y = \frac{p'}{P}$                 | 1                                    | $d_v = \frac{0.002167p'}{T}$                   |
| Volumetric humidity $d_v$ (kg·m <sup>-3</sup> )         | $Y = \frac{0.622}{\frac{0.002167P}{d_v T} - 1}$ | $z = \frac{1}{\frac{0.002167P}{d_v T} - 1}$ | $Y_w = \frac{0.622}{\frac{0.002167P}{d_v T} - 0.378}$ | $y = \frac{461.5d_v T}{P}$         | $p' = 461.5d_v T$                    | 1                                              |

<sup>a</sup> Multiply  $Y$  by 10<sup>6</sup> to obtain ppm<sub>w</sub>; multiply  $z$  by 10<sup>6</sup> to obtain ppm<sub>v</sub>

### 4.9.3 Saturation vapour pressure $p_s$

The saturation vapour pressure of a pure liquid varies with temperature. For accurate calculation of saturation vapour pressure of water, the formula given by Sonntag (1990) should be used (equation (1)) [1]. With  $p_s$  in Pascals ( $\text{N}\cdot\text{m}^{-2}$ ) at absolute temperature  $T$ ,

$$\ln p_s = -6096.9385T^{-1} + 21.2409642 - 2.711193 \times 10^{-2}T + 1.673952 \times 10^{-5}T^2 + 2.433502 \ln T \quad (1)$$

A similar formula applies for saturation vapour pressure over ice – see BS 1339-1. However, simpler (but less accurate) formulae exist, such as the Antoine equation. This is easier to use, especially as it is directly reversible to give  $T$  in terms of  $p_s$ :

$$\ln p_s = C_0 - \frac{C_1}{T - C_2} \quad T = \frac{C_1}{C_0 - \ln p_s} + C_2 \quad (2)$$

The Antoine equation, with its commonly quoted values for coefficients  $C_0$ ,  $C_1$  and  $C_2$ , gives results within 0.1 % of steam tables and the Sonntag equation (1) over the range 50 °C to 100 °C, but shows a significant error at lower values (nearly 3 % at 0 °C). By slightly changing the coefficients to give a close fit at 0 °C and 100 °C, an alternative fit can be obtained with an error of less than 1.2 % over the complete range 0 °C to –100 °C, although of course the errors at higher temperatures will be greater than with the original coefficients. The coefficients are shown in Table 3.

**Table 3 — Antoine equation coefficients for air–water system**

|                 |          | $C_0$    | $C_1$    | $C_2$<br>K |             | $C_0$    | $C_1$    | $C_2$<br>K |
|-----------------|----------|----------|----------|------------|-------------|----------|----------|------------|
| Standard values | $p$ (Pa) | 23.196 3 | 3 816.44 | 46.13      | $p$ (mm Hg) | 18.303 6 | 3 816.44 | 46.13      |
| New values      | $p$ (Pa) | 23.19    | 3 830    | 44.83      | $p$ (mm Hg) | 18.3     | 3 830    | 44.87      |

For vapours other than water, the Sonntag equation cannot be used, but coefficients are available for the Antoine equation for a wide variety of vapours in the book “The Properties of Gases and Liquids” [2].

Another commonly used alternative form is the Magnus equation. Like the Antoine equation, this is easily reversible:

$$\text{Over water: } \ln p_s = \ln 611.2 + \frac{17.62t_{dp}}{t_{dp} + 243.12} \quad t_{dp} = \frac{243.12 \ln(p_s / 611.2)}{17.62 - \ln(p_s / 611.2)} \quad (3)$$

$$\text{Over ice: } \ln p_s = \ln 611.2 + \frac{22.46t_{fp}}{t_{fp} + 272.62} \quad t_{fp} = \frac{272.62 \ln(p_s / 611.2)}{22.46 - \ln(p_s / 611.2)} \quad (4)$$

The Sonntag equation strictly only applies to water vapour with no other gases present (i.e. in a partial vacuum). The actual saturation vapour pressure  $p_s'$  of a gas mixture, e.g. water vapour in air, is given by multiplying the pure saturation vapour pressure  $p_s$  by an enhancement factor  $f$ , for which various equations are given in part 1. Likewise, the enhancement factor can be applied to convert pure vapour pressure  $p$  for unsaturated mixtures to actual vapour pressure  $p'$ . For water vapour in air at one atmosphere, 101 325 Pa,  $f \approx 1.004$  7. Hence, for most purposes, the correction is negligible, and except for accurate calculations,  $p_s$  and  $p_s'$  are interchangeable, as are  $p$  and  $p'$ . Alternatively,  $f$  can often be applied simply by taking it to be constant at a given total pressure, as temperature has only a weak effect on  $f$  at near-ambient conditions. However,  $f$  is strongly dependent on pressure, and should always be included for calculations at elevated pressure; for example,  $f \approx 1.03$  at 10 bar and  $f \approx 1.3$  at 100 bar.