

---

---

**Plastics — Methods for determining  
the density of non-cellular plastics —**

**Part 1:**

**Immersion method, liquid pycnometer  
method and titration method**

*Plastiques — Méthodes de détermination de la masse volumique des  
plastiques non alvéolaires —*

*Partie 1: Méthode par immersion, méthode du pycnomètre en milieu  
liquide et méthode par titrage*

MAHCO





**COPYRIGHT PROTECTED DOCUMENT**

© ISO 2019

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office  
CP 401 • Ch. de Blandonnet 8  
CH-1214 Vernier; Geneva  
Phone: +41 22 749 01 11  
Fax: +41 22 749 09 47  
Email: [copyright@iso.org](mailto:copyright@iso.org)  
Website: [www.iso.org](http://www.iso.org)

Published in Switzerland

## Contents

Page

Foreword.....	iv
<b>1 Scope.....</b>	<b>1</b>
<b>2 Normative references.....</b>	<b>1</b>
<b>3 Terms and definitions.....</b>	<b>1</b>
<b>4 Conditioning.....</b>	<b>2</b>
<b>5 Methods.....</b>	<b>2</b>
5.1 Method A — Immersion method.....	2
5.1.1 Apparatus.....	2
5.1.2 Immersion liquid.....	3
5.1.3 Specimens.....	3
5.1.4 Procedure.....	3
5.2 Method B — Liquid pycnometer method.....	4
5.2.1 Apparatus.....	4
5.2.2 Immersion liquid.....	5
5.2.3 Specimens.....	5
5.2.4 Procedure.....	5
5.3 Method C — Titration method.....	6
5.3.1 Apparatus.....	6
5.3.2 Immersion liquids.....	6
5.3.3 Specimens.....	6
<b>6 Correction for buoyancy in air.....</b>	<b>7</b>
<b>7 Test report.....</b>	<b>8</b>
<b>Annex A (informative) Liquid systems suitable for use in Method C.....</b>	<b>9</b>
<b>Annex B (informative) Correction for buoyancy in air.....</b>	<b>10</b>
<b>Bibliography.....</b>	<b>12</b>

MAHCO



## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 5, *Physical-chemical properties*.

This third edition cancels and replaces the second edition (ISO 1183-1:2012), which has been technically revised. The main changes compared to the previous edition are as follows:

- the buoyancy correction has been revised.

A list of all parts in the ISO 1183 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

MAHCO

# Plastics — Methods for determining the density of non-cellular plastics —

## Part 1:

## Immersion method, liquid pycnometer method and titration method

**WARNING** — The use of this document might involve hazardous materials, operations or equipment. This document does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this document to establish appropriate health and safety practices.

### 1 Scope

This document specifies three methods for the determination of the density of non-cellular plastics in the form of void-free moulded or extruded objects, as well as powders, flakes and granules.

- Method A: Immersion method, for solid plastics (except for powders) in void-free form.
- Method B: Liquid pycnometer method, for particles, powders, flakes, granules or small pieces of finished parts.
- Method C: Titration method, for plastics in any void-free form.

**NOTE** Density is frequently used to follow variations in physical structure or composition of plastic materials. Density can also be useful in assessing the uniformity of samples or specimens. Often, the density of plastic materials depend upon the choice of specimen preparation method. When this is the case, precise details of the specimen preparation method are intended to be included in the appropriate material specification. This note is applicable to all three methods.

### 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 291, *Plastics — Standard atmospheres for conditioning and testing*

ISO 472, *Plastics — Vocabulary*

### 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 472 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>



ISO 1183-1:2019(E)

**3.1  
mass**

$m$   
quantity of matter contained in a body

Note 1 to entry: It is expressed in kilograms (kg) or grams (g).

**3.2  
apparent mass**

$m_{APP}$   
mass of a body obtained by measuring its weight using an appropriately calibrated balance

Note 1 to entry: It is expressed in kilograms (kg) or grams (g).

**3.3  
density**

$\rho$   
ratio of the mass  $m$  of a sample to its volume  $V$  (at the temperature  $T$ ), expressed in kg/m<sup>3</sup>, kg/dm<sup>3</sup> (g/cm<sup>3</sup>) or kg/l (g/ml)

Note 1 to entry: The following terms, based upon ISO 80000-4[1], are given in [Table 1](#) for clarification.

**Table 1 — Density terms**

Term	Symbol	Formulation	Units
Density	$\rho$	$m/V$	kg/m <sup>3</sup> kg/dm <sup>3</sup> (g/cm <sup>3</sup> ) kg/l (g/ml)
Specific volume	$v$	$V/m (= 1/\rho)$	m <sup>3</sup> /kg dm <sup>3</sup> /kg (cm <sup>3</sup> /g) l/kg (ml/g)

**4 Conditioning**

The test atmosphere shall be in accordance with ISO 291. In general, conditioning specimens to constant temperature is not required, because the determination itself brings the specimen to the constant temperature of the test.

Specimens which change in density during the test to such an extent that the change is greater than the required accuracy shall be conditioned prior to measurement in accordance with the applicable material specification. When changes in density with time or atmospheric conditions are the primary purpose of the measurements, the specimens shall be conditioned as described in the material specification and, if no material specification exists, then as agreed upon by the interested parties.

**5 Methods**

**5.1 Method A — Immersion method**

**5.1.1 Apparatus**

**5.1.1.1 Analytical balance or instrument specifically designed for measurement of density, accurate to  $\pm 0,1$  mg.**

An automatically operating instrument may be used. The calculation of density may be done automatically using a computer or software integrated into the analytical balance.

**5.1.1.2 Immersion vessel:** a beaker or other wide-mouthed container of suitable size for holding the immersion liquid.

**5.1.1.3 Stationary support,** e.g. a pan straddle, to hold the immersion vessel above the balance pan.

**5.1.1.4 Thermometer,** graduated at 0,1 °C intervals, covering the range 0 °C to 30 °C.

**5.1.1.5 Wire** (if required), corrosion-resistant, of diameter not greater than 0,5 mm, for suspending specimens in the immersion liquid.

**5.1.1.6 Sinkers,** of suitable mass to ensure complete immersion of the specimen, for use when the density of the specimen is less than that of the immersion liquid.

**5.1.1.7 Pycnometer,** with a side-arm overflow capillary, for determining the density of the immersion liquid when this liquid is not water. The pycnometer shall be equipped with a thermometer graduated at 0,1 °C intervals from 0 °C to 30 °C.

**5.1.1.8 Liquid bath,** capable of being thermostatically controlled to within  $\pm 0,5$  °C, for use in determining the density of the immersion liquid.

## 5.1.2 Immersion liquid

Use freshly distilled or deionized water, or another suitable liquid, containing not more than 0,1 % of a wetting agent to help in removing air bubbles. The liquid or solution with which the specimen comes into contact during the measurement shall have no effect on the specimen.

The density of immersion liquids other than distilled water need not be measured provided they are obtained from an accredited source and are accompanied by a certificate.

## 5.1.3 Specimens

Specimens may be in any void-free form except for powder. They shall be of a convenient size to give adequate clearance between the specimen and the immersion vessel and should preferably have a mass of at least 1 g.

When cutting specimens from larger samples, proper equipment shall be used to ensure that the characteristics of the material do not change. The surface of the specimen shall be smooth and free from cavities to minimize the entrapment of air bubbles upon immersion in the liquid, otherwise errors will be introduced.

## 5.1.4 Procedure

**5.1.4.1** Weigh the specimen, to the nearest 0,1 mg, in air while suspended with a wire of maximum diameter 0,5 mm. Record the mass of the specimen.

**5.1.4.2** Immerse the specimen, still suspended by the wire, in the immersion liquid (5.1.2), contained in the immersion vessel (5.1.1.2) on the support (5.1.1.3). The temperature of the immersion liquid shall be  $23\text{ °C} \pm 2\text{ °C}$  (or  $27\text{ °C} \pm 2\text{ °C}$ ). Remove any adhering air bubbles with a fine wire. Weigh the immersed specimen to the nearest 0,1 mg.

If the measurement is carried out in a temperature-controlled room, the temperature of the whole apparatus, including the immersion liquid, shall be within the range  $23\text{ °C} \pm 2\text{ °C}$  (or  $27\text{ °C} \pm 2\text{ °C}$ ).

**5.1.4.3** If necessary, determine the density of immersion liquids other than water as follows. Weigh the pycnometer (5.1.1.7) empty and then containing freshly distilled or deionized water at a temperature of  $23\text{ °C} \pm 0,5\text{ °C}$  (or  $27\text{ °C} \pm 0,5\text{ °C}$ ). Weigh the same pycnometer, after cleaning and drying, filled with the



ISO 1183-1:2019(E)

immersion liquid [also at a temperature of  $23\text{ °C} \pm 0,5\text{ °C}$  (or  $27\text{ °C} \pm 0,5\text{ °C}$ )]. Use the liquid bath (5.1.1.8) to bring the water and immersion liquid to the correct temperature. Calculate the density,  $\rho_{IL}$ , in grams per cubic centimetre, of the immersion liquid at  $23\text{ °C}$  (or  $27\text{ °C}$ ), using Formula (1):

$$\rho_{IL} = \frac{m_{IL}}{m_W} \times \rho_W \quad (1)$$

where

$m_{IL}$  is the mass of the immersion liquid, in g;

$m_W$  is the mass of the water, in g;

$\rho_W$  is the density of water at  $23\text{ °C}$  (or  $27\text{ °C}$ ), in  $\text{g/cm}^3$ .

5.1.4.4 Calculate the density,  $\rho_S$ , in grams per cubic centimetre, of the specimen at  $23\text{ °C}$  (or  $27\text{ °C}$ ), using Formula (2):

$$\rho_S = \frac{m_{S,A} \times \rho_{IL}}{m_{S,A} - m_{S,IL}} \quad (2)$$

where

$m_{S,A}$  is the apparent mass of the specimen in air, in g;

$m_{S,IL}$  is the apparent mass of the immersion liquid, in g;

$\rho_{IL}$  is the density of the immersion liquid at  $23\text{ °C}$  (or  $27\text{ °C}$ ) as stated by the supplier or determined as specified in 5.1.4.3, in  $\text{g/cm}^3$ .

For specimens having a density below that of the immersion liquid, the test may be performed in exactly the same way as described above, with the following exception: a sinker of lead or other dense material is attached to the wire, such that the sinker rests below the liquid level, as does the specimen, during immersion. The sinker may be considered a part of the suspension wire. In this case, the uplift exerted by the immersion liquid on the sinker shall be allowed for by using Formula (3), rather than Formula (2), to calculate the density of the specimen:

$$\rho_S = \frac{m_{S,A} \times \rho_{IL}}{m_{S,A} + m_{K,IL} - m_{S+K,IL}} \quad (3)$$

where

$m_{K,IL}$  is the apparent mass of the sinker in the immersion liquid, in g;

$m_{S+K,IL}$  is the apparent mass of the specimen and sinker in the immersion liquid, in g.

The buoyancy of the suspension wire in air is normally considered to be negligible, but, for correction for air buoyancy, see Clause 6.

5.1.4.5 Perform the test on a minimum of three specimens and calculate the mean result to three decimal places.

## 5.2 Method B — Liquid pycnometer method

### 5.2.1 Apparatus

5.2.1.1 **Balance**, accurate to  $\pm 0,1\text{ mg}$ .



5.2.1.2 **Stationary support** (5.1.1.3).

5.2.1.3 **Pycnometer** (5.1.1.7).

5.2.1.4 **Liquid bath** (5.1.1.8).

5.2.1.5 **Dessicator**, connected to a vacuum system.

## 5.2.2 Immersion liquid

As specified in 5.1.2.

## 5.2.3 Specimens

Specimens of powders, granules or flakes shall be measured in the form in which they are received. The specimen mass shall be in the range of 1 g to 5 g.

## 5.2.4 Procedure

5.2.4.1 Weigh the pycnometer (5.2.1.3) empty and dry. Weigh a suitable quantity of the plastic material in the pycnometer. Cover the test specimen with immersion liquid (5.2.2) and remove all the air by placing the pycnometer in the desiccator (5.2.1.5) and applying a vacuum. Break the vacuum and almost completely fill the pycnometer with immersion liquid. Bring it to constant temperature [23 °C ± 0,5 °C (or 27 °C ± 0,5 °C)] in the liquid bath (5.2.1.4) and then complete filling exactly to the limit of the capacity of the pycnometer.

Wipe dry and weigh the pycnometer with the specimen and immersion liquid.

5.2.4.2 Empty and clean the pycnometer. Fill it with deaerated distilled or deionized water, remove any remaining air as above, and determine the mass of the pycnometer and its contents at the temperature of test.

5.2.4.3 Repeat the process with the immersion liquid if an immersion liquid other than water was used, and determine its density as specified in 5.1.4.3.

5.2.4.4 Calculate the density  $\rho_S$ , in grams per cubic centimetre, of the specimen at 23 °C (or 27 °C), using Formula (4):

$$\rho_S = \frac{m_S \times \rho_{IL}}{m_1 - m_2} \quad (4)$$

where

$m_S$  is the apparent mass of the specimen, in g;

$m_1$  is the apparent mass of the liquid required to fill the empty pycnometer, in g;

$m_2$  is the apparent mass of the liquid required to fill the pycnometer containing the specimen, in g;

$\rho_{IL}$  is the density of the immersion liquid at 23 °C (or 27 °C) as stated by the supplier or determined as specified in 5.1.4.3, in g/cm<sup>3</sup>,

5.2.4.5 Perform the test on a minimum of three specimens and calculate the mean result to three decimal places.

### 5.3 Method C — Titration method

#### 5.3.1 Apparatus

5.3.1.1 **Liquid bath** ([5.1.1.8](#)).

5.3.1.2 **Glass cylinder**, capacity 250 ml.

5.3.1.3 **Thermometer**, graduated at 0,1 °C intervals, with a range suitable for measuring the test temperature used.

5.3.1.4 **Volumetric flask**, capacity 100 ml.

5.3.1.5 **Flat-tipped glass rod stirrer**.

5.3.1.6 **Burette**, capacity 25 ml, of a design which enables it to be kept in the liquid bath ([5.3.1.1](#)), capable of dispensing 0,1 ml portions of liquid.

#### 5.3.2 Immersion liquids

Required are two miscible liquids of different densities. One shall have a density just below that of the test material and the other a density higher than that of the test material. Densities of various liquids are given in [Annex A](#) as a guide. If necessary, carry out a rapid preliminary test in a few millilitres of the liquid.

The liquid with which the specimen comes into contact during the measurement shall have no effect on the specimen.

#### 5.3.3 Specimens

Specimens shall be in a suitable void-free form.

#### 5.3.4 Procedure

5.3.4.1 By means of the volumetric flask ([5.3.1.4](#)), accurately measure 100 ml of the less dense immersion liquid (see [5.3.2](#)) into the clean, dry 250 ml glass cylinder ([5.3.1.2](#)). Put the cylinder into the liquid bath ([5.3.1.1](#)) controlled at  $23\text{ °C} \pm 0,5\text{ °C}$  (or  $27\text{ °C} \pm 0,5\text{ °C}$ ).

5.3.4.2 Place the pieces of the test specimen in the cylinder. They shall fall to the bottom and be free of air bubbles. Allow the cylinder and its contents to stabilize at the bath temperature, stirring at intervals.

It is recommended that the thermometer ([5.3.1.3](#)) be kept permanently in the liquid. This makes it possible to check that thermal equilibrium is attained at the time of measurement and, in particular, that the heat of dilution has been dissipated.

5.3.4.3 When the temperature of the liquid is  $23\text{ °C} \pm 0,5\text{ °C}$  (or  $27\text{ °C} \pm 0,5\text{ °C}$ ), add the more dense immersion liquid millilitre by millilitre from the burette ([5.3.1.6](#)). Stir the liquid after each addition by means of the glass rod ([5.3.1.5](#)), held vertically, and avoid producing air bubbles.

After each addition of the denser liquid and mixing, observe the behaviour of the pieces of test specimen.

At first, they will fall rapidly to the bottom but, as more of the denser liquid is added, their rate of fall will become slower. At this point, add the denser liquid in 0,1 ml amounts. Note the total amount of more dense liquid added when the lightest pieces of specimen become suspended within the liquid, at the level to which they are brought by stirring, without moving up or down for at least 1 min. At this point in the titration, note the amount of more dense liquid required.



Add more of the denser liquid until the heaviest pieces of specimen remain at a constant level within the liquid for at least 1 min. Note the amount of more dense liquid required.

For each pair of liquids, establish the relationship between the amount of more dense liquid added and the density of the resulting mixture, and plot the relationship in the form of a graph.

The density of the liquid mixture at each point on the graph can be determined by a pycnometer method.

## 6 Correction for buoyancy in air

Where weighings are made in air, the values of the “apparent masses” obtained shall be corrected to compensate for the effect of the air buoyancy on the specimen (and any sinker used) and on the balance weights used. This will be the case if the accuracy of the results is to be between 0,2 % and 0,05 %.

The true mass,  $m_T$ , in grams, is calculated using the [Formula \(5\)](#):

$$m_T = m_{APP} \cdot \left( 1 + \frac{\rho_a}{\rho_S} - \frac{\rho_a}{\rho_L} \right) \quad (5)$$

where

$m_{APP}$  is the apparent mass, in g;

$\rho_a$  is the density of air (approximately 0,001 2 g/cm<sup>3</sup> at 23 °C/50 % RH and at 27 °C/65 % RH), in g/cm<sup>3</sup>;

$\rho_S$  is the density of the specimen (or any sinker used) at 23 °C (or 27 °C), in g/cm<sup>3</sup>;

$\rho_L$  is the density of the balance weights used, in g/cm<sup>3</sup>.

For improved accuracy, the dependence of the density of air on pressure needs to be taken into account. The density of the air can be calculated using [Formula \(6\)](#) derived based on the ideal gas law.

$$\rho_a = \frac{\left( P_{ha} - \frac{RH}{100} \cdot P_{V,sat} \right) \cdot M_a + \frac{RH}{100} \cdot P_{V,sat} \cdot M_{H_2O}}{R \cdot (273,15 + T)} \quad (6)$$

where

$\rho_a$  is the density of humid air, in g/cm<sup>3</sup>;

$P_{ha}$  is the partial pressure of humid air, in MPa;

$RH$  is the relative humidity, in %;

$P_{V,sat}$  is the partial pressure of saturated water vapour, in MPa;

$M_a$  is the molecular mass of air, in g/mol;

$M_{H_2O}$  is the molecular mass of water vapour, in g/mol;

$R$  is the universal gas constant (8,314 47 J/mol K);

$T$  is the temperature in °C.

Approximation of saturated water vapour pressure, as shown in [Formula \(7\)](#), can be done using Tetens equation[2]:

$$P_{V,\text{sat}} = C_0 \times \exp\left(\frac{C_1 \times T}{C_2 + T}\right) \quad (7)$$

where

$C_0$  0,610 78;

$C_1$  17,27;

$C_2$  237,3.

See [Annex B](#) for the derivation of [Formulae \(5\)](#) to [\(7\)](#).

## 7 Test report

The test report shall include the following information:

- a) a reference to this document, i.e. ISO 1183-1:2019;
- b) all details necessary for complete identification of the material tested, including specimen preparation method and pretreatment, if applicable;
- c) the method used (A, B or C);
- d) the immersion liquid(s) used;
- e) the test temperature (23 °C or 27 °C);
- f) the individual values and arithmetic mean of the density;
- g) a statement as to whether any buoyancy correction was made and, if so, what kind of correction;
- h) the date of the test.

MAHCO



## Annex A (informative)

### Liquid systems suitable for use in Method C

**WARNING** — Some of the chemicals given in [Table A.1](#) might be hazardous.

**Table A.1 — Liquid systems for Method C**

System	Density range g/cm <sup>3</sup>
Methanol/benzyl alcohol	0,79 to 1,05
Isopropanol/water	0,79 to 1,00
Isopropanol/diethylene glycol	0,79 to 1,11
Ethanol/water	0,79 to 1,00
Toluene/carbon tetrachloride	0,87 to 1,60
Water/aqueous solution of sodium bromide <sup>a</sup>	1,00 to 1,41
Water/aqueous solution of calcium nitrate	1,00 to 1,60
Ethanol/aqueous solution of zinc chloride <sup>b</sup>	0,79 to 1,70
Carbon tetrachloride/1,3-dibromopropane	1,60 to 1,99
1,3-Dibromopropane/ethylene bromide	1,99 to 2,18
Ethylene bromide/bromoform	2,18 to 2,89
Carbon tetrachloride/bromoform	1,60 to 2,89
Isopropanol/methylglycol acetate	0,79 to 1,00

<sup>a</sup> A density of 1,41 is equivalent to a mass fraction of about 40 % sodium bromide.

<sup>b</sup> A density of 1,70 is equivalent to a mass fraction of about 67 % zinc chloride.

The following may also be used in various mixtures:

	Density (g/cm <sup>3</sup> )
<i>n</i> -Octane	0,70
Dimethylformamide	0,94
Tetrachloroethane	1,60
Ethyl iodide	1,93
Methylene iodide	3,33

## Annex B (informative)

### Correction for buoyancy in air

[Formula \(5\)](#) in [Clause 6](#) for the true mass  $m_T$  of the specimen (or any sinker used) can be derived as follows.

[Formula \(B.1\)](#) relates the mass of the specimen (or any sinker used) and the mass of the balance weights necessary at the balance point:

$$m_T - \rho_a \cdot \frac{m_{APP}}{\rho_S} = m_B - \rho_a \cdot \frac{m_B}{\rho_L} \quad (B.1)$$

where

- $m_T$  is the true mass of the specimen (or any sinker used), in g;
- $m_{APP}$  is the apparent mass of the specimen (or any sinker used), in g;
- $m_B$  is the mass of the balance weights, in g;
- $\rho_a$  is the density of air, in g/cm<sup>3</sup>;
- $\rho_S$  is the density of the specimen (or any sinker used), in g/cm<sup>3</sup>;
- $\rho_L$  is the density of the balance weights, in g/cm<sup>3</sup>.

Rearrangement of [Formula \(B.1\)](#) gives:

$$m_T = m_B + m_{APP} \cdot \frac{\rho_a}{\rho_S} - m_B \cdot \frac{\rho_a}{\rho_L} \quad (B.2)$$

As the buoyancy effect of air is very small,  $m_{APP}$  can be assumed to be equal to  $m_B$  and [Formula \(B.2\)](#) can be simplified to give [Formula \(B.3\)](#):

$$m_T = m_{APP} \cdot \left( 1 + \frac{\rho_a}{\rho_S} - \frac{\rho_a}{\rho_L} \right) \quad (B.3)$$

Based on the ideal gas law, i.e. additivity of all components, the density of humid air can be expressed as the sum of the density of dry air and that of water vapour as given in [Formula \(B.4\)](#):

$$\rho_{ha} = \frac{P_a \cdot M_a}{R \cdot (273,15 + T)} + \frac{P_{H_2O} \cdot M_{H_2O}}{R \cdot (273,15 + T)} \quad (B.4)$$

where

- $\rho_{ha}$  is the density of humid air, in g/cm<sup>3</sup>;
- $P_a$  is the partial pressure of dry air, in MPa;
- $M_a$  is the molecular mass of air, in g/mol;



- $P_{H_2O}$  is the partial pressure of water vapour, in MPa;  
 $M_{H_2O}$  is the molecular mass of water vapour, in g/mol;  
 $R$  is the universal gas constant (8,314 47 J/(mol K));

The partial pressure of water vapour is given by its saturation pressure multiplied by relative humidity RH and the partial pressure of dry air is the total pressure minus water vapour pressure as shown in [Formula \(B.5\)](#):

$$\rho_a = \frac{\left( P_{ha} - \frac{RH}{100} \cdot P_{V,sat} \right) \cdot M_a + \frac{RH}{100} \cdot P_{V,sat} \cdot M_{H_2O}}{R \cdot (273,15 + T)} \quad (B.5)$$

where

- $P_{ha}$  is the pressure of humid air in MPa;  
 $RH$  is the relative humidity, in %;  
 $P_{V,sat}$  is the partial pressure of saturated water vapour, in MPa.

Approximation of saturated water vapour pressure can be done via the Tetens equation<sup>[2]</sup> given in [Formula \(B.6\)](#) which is the best compromise between accuracy and ease of use:

$$P_{V,sat} = C_0 \times \exp\left(\frac{C_1 \times T}{C_2 + T}\right) \quad (B.6)$$

where

- $C_0$  0,610 78;  
 $C_1$  17,27;  
 $C_2$  237,3.

MAHCO

## Bibliography

- [1] ISO 80000-4, *Quantities and units — Part 4: Mechanics*
- [2] MONTEITH J.L., & UNSWORTH M.H. *Principles of Environmental Physics*. Third Ed. Academic Press, Amsterdam, 2007





