BRITISH STANDARD

BS ISO 8778:2003

Pneumatic fluid power — Standard reference atmosphere

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The UK participation in its preparation was entrusted to Technical Committee MCE/18, Fluid power systems and components, which has the responsibility to:

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— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

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INTERNATIONAL STANDARD

ISO 8778

Second edition
2003-03-15

Pneumatic fluid power — Standard reference atmosphere

Transmissions pneumatiques — Atmosphère normalisée de référence

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Foreword

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ISO 8778 was prepared by Technical Committee ISO/TC 131, *Fluid power systems*, Subcommittee SC 5, *Control products and components*.

This second edition cancels and replaces the first edition (ISO 8778:1990), which has been technically revised.

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Introduction

In pneumatic fluid power systems, power is transmitted and controlled through a gas, most commonly compressed air, under pressure within a circuit. When presenting characteristics of pneumatic components, equipment or systems that use compressed air, it is necessary to have a standard reference atmosphere to permit comparison of data obtained under various pressure conditions.

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Pneumatic fluid power — Standard reference atmosphere

1 Scope

This International Standard specifies a standard atmospheric reference value to be used in pneumatic fluid power technology for stating the performance data of components and systems.

2 Normative references

The following referenced 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.

ISO 5598, *Fluid power systems and components — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5598 and the following apply.

3.1
atmosphere
ambient conditions defined by one or more of the following parameters: temperature, relative humidity, pressure

3.2
reference atmosphere
agreed atmosphere to which conditions determined in other atmospheres may be related by using suitable conversion factors

NOTE 1 The term “other atmospheres” can mean pressurized or vacuum conditions.

NOTE 2 See Annex A for a discussion of alternative reference atmospheres.

3.3
standard reference atmosphere
atmosphere whose pressure has been approximated to be nearly that at sea level, whose temperature is typically considered to be room temperature and whose relative humidity is arbitrarily established

4 Standard reference atmosphere

4.1 The standard reference atmosphere shall be as defined in Table 1.

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Table 1 — Definition of standard reference atmosphere

Pressure	Temperature	Relative humidity
100 kPa (1 bar)	20 °C	65 %
NOTE This is the same reference atmosphere as that given in ISO 8778:1990.		

4.2 For gases, when the quantity is expressed as free gas, the abbreviation ANR (standard reference atmosphere), in parentheses, shall follow the unit, not the value, for example:

$q_V = x$ m^3/s (ANR)

5 Identification statement (Reference to this International Standard)

Manufacturers are strongly recommended to use the following statement in their catalogues, test reports and sales literature when electing to comply with this International Standard:

"Standard reference atmosphere conforms to ISO 8778:2003, *Pneumatic fluid power — Standard reference atmosphere*."

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Annex A
(informative)

Alternative reference atmospheres and determination of humidity and density

A.1 Introduction

This annex provides two additional categories of reference atmospheres for informative purposes only. In addition, equations for calculating humidity and density are also included.

A.2 Description and application of alternative reference atmospheres

A.2.1 Conversion reference atmosphere

The conversion reference atmosphere is a reference atmosphere whose pressure is considered to be atmospheric pressure at sea level, whose temperature is typically considered to be room temperature and whose relative humidity is calculated to be equivalent to that existing at the conditions at which the conversion originates (see Table A.1). The conversion reference atmosphere is considered to be the most accurate for pressure conversions and density calculations.

A.2.2 Engineering reference atmosphere

The engineering reference atmosphere is a reference atmosphere whose pressure is rounded off to a number that provides for very convenient calculations, whose temperature is typically considered to be room temperature and whose relative humidity is assumed to be 0 %. The engineering reference atmosphere is typically used in cases where the effect of relative humidity is ignored.

A.3 Specification of alternative reference atmospheres

The conversion reference atmosphere and engineering reference atmosphere are as defined in Table A.1.

Table A.1 – Definitions of conversion reference atmosphere and engineering reference atmosphere

Type of alternative reference atmosphere	Pressure	Temperature	Relative humidity
Conversion reference atmosphere (ACR – RH %)	760 mm Hg absolute 100,96 kPa[a] (1,009 6 bar)	20 °C	Equivalent to that existing at the conditions at which the conversion originates
Engineering reference atmosphere (AER)	100 kPa (1 bar)	20 °C	0 %

[a] The value of 100,96 kPa is a conversion from 760 mm Hg, using the density of Hg at 20 °C.

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A.4 Determination of equivalent relative humidity and density at atmospheric conditions

A.4.1 Symbols and constants

The following symbols and constants are used in determining equivalent relative humidity and density at atmospheric conditions.

NOTE All pressures are absolute.

p_0 = atmospheric pressure

p_1 = pressure of the compressed state

p_{s0} = saturation pressure of the water vapour at atmospheric temperature

p_{s1} = saturation pressure of the water vapour at the temperature of the compressed state

R_a = 287 m^2/s^2K (gas constant for dry air)

R_{wv} = 461,45 m^2/s^2K (gas constant for water vapour)

T_0 = absolute temperature of the atmosphere

ϕ_0 = relative humidity of the air at atmospheric conditions if it contains all the water vapour from the compressed state

ϕ_1 = relative humidity of the air in the compressed state

A.4.2 Equivalent relative humidity

A relationship between the relative humidity in the compressed state and the relative humidity at atmospheric conditions, assuming that none of the water vapour is condensed, can be stated as follows:

$$\phi_0 = \phi_1 \left(\frac{p_0}{p_1} \right) \left(\frac{p_{s1}}{p_{s0}} \right)$$

If the result is greater than 100 %, water vapour has condensed and the calculation is limited to 100 %.

A.4.3 Density at atmospheric conditions

The density of air expanded to atmospheric conditions from a pressurized state (line conditions), including the relative humidity at line conditions carried to atmospheric conditions (assuming that none of the water vapour condenses) is:

$$\rho_0 = \frac{p_0}{R_a T_0} - \phi_1 \left(\frac{p_0}{p_1} \right) \frac{p_{s1}}{T_0} \left(\frac{1}{R_a} - \frac{1}{R_{wv}} \right)$$

A.5 Analysis of errors

The simplification of pressure in the engineering reference atmosphere can introduce an error of about 1 %. However, this is to be assessed in applications where use of the pressure term may be non-linear, as in flow and thermodynamic calculations.

Annex B describes the errors introduced from relative humidity considerations.

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Annex B
(informative)

Development of equations for relative humidity, density and error analysis

B.1 Statement of the problem

When compressed air in a container or conduit is equated to its atmospheric equivalent, the water vapour content is often ignored in the calculation process. However, the change of state will affect the density at atmospheric conditions. Although the density change may not affect an equivalent-state calculation (pressure and temperature), the water content could be important in those calculations where the change affects system calculations, such as a dehumidifying process.

The following analysis develops equations for determining the relative humidity and density at atmospheric conditions for a mixture of air and water vapour at pressurized conditions.

B.2 Symbols and constants

Symbols and constants used in the following equations:

NOTE All pressures and temperatures are absolute.

M_a = 28,967 g/mole (molecular weight of dry air)

M_{wv} = 18,016 g/mole (molecular weight of water vapour)

m = mass of mixture

m_a = mass of dry air

m_{wv} = mass of water vapour

p_0 = pressure of the atmosphere (mixture of air and water vapour)

p_1 = pressure of mixture of air and water vapour in the compressed state

p_{a0} = partial pressure of the dry air at atmospheric conditions

p_{a1} = partial pressure of the dry air in the compressed state

p_{wv1} = partial pressure of the water vapour in the compressed state

p_{wv0} = partial pressure of the water vapour at atmospheric conditions, if it contained all the water vapour from the compressed state

p_{s0} = saturation pressure of the water vapour at atmospheric temperature

p_{s1} = saturation pressure of the water vapour at the temperature of the compressed state

R_a = 287 m^2/s^2K (gas constant for dry air)

R_{wv} = 461,45 m^2/s^2K (gas constant for water vapour)

T_0 = temperature of the atmosphere

T_1 = temperature of the compressed state

V = volume of mixture

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ϕ_0 = relative humidity of the air at atmospheric conditions if it contained all the water vapour from the compressed state

ϕ_1 = relative humidity of the air in the compressed state

ϕ'_0 = arbitrarily specified relative humidity of the air at atmospheric conditions

ρ_0 = density of the mixture at atmospheric conditions with relative humidity equivalent to the compressed state

ρ'_0 = density of the mixture at atmospheric conditions with arbitrary relative humidity

B.3 Relative humidity

In general, the pressure of an air/water vapour mixture is the sum of its two partial pressures:

$$p_{\text{mixture}} = p_{\text{dry air}} + p_{\text{water vapour}}$$

Using the symbols and constants given above, the following can be stated for both compressed and atmospheric conditions:

$$p_{a1} = p_1 - p_{wv1} \text{ and } p_{a0} = p_0 - p_{wv0} \qquad \text{(B.1)}$$

From the definition of relative humidity (at compressed and at atmospheric conditions):

$$\phi_1 = p_{wv1}/p_{s1} \text{ and } \phi_0 = p_{wv0}/p_{s0}$$

The partial pressures of the water vapour then become:

$$p_{wv1} = \phi_1 p_{s1} \text{ and } p_{wv0} = \phi_0 p_{s0} \qquad \text{(B.2)}$$

If it is assumed that none of the water vapour will condense, the specific humidity will be the same at compressed and atmospheric conditions. Then, the following will hold:

$$\frac{p_{wv1} M_{wv}}{p_{a1} M_a} = \frac{p_{wv0} M_{wv}}{p_{a0} M_a}$$

Substituting equations (B.1) and (B.2) into this and solving for ϕ_0 yields:

$$\phi_0 = \phi_1 (p_0/p_1)\,(p_{s1}/p_{s0}) \qquad \text{(B.3)}$$

If the assumption of no condensation is not true, the above result will be greater than 100 %. This is an indication that the calculation is not valid. In this case, the relative humidity will only be 100 %.

B.4 Density

The density of mixed air at atmospheric conditions is composed of two parts, and an equation of state can be written for each part as follows:

$$p_{a0} V = m_a R_a T_0 \text{ and } p_{wv0} V = m_{wv} R_{wv} T_0$$

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The mass of the mixture will be equal to the sum of the mass of each component:

$$m = m_{\mathrm{a}} + m_{\mathrm{wv}} = \frac{p_{\mathrm{a0}} V}{R_{\mathrm{a}} T_0} + \frac{p_{\mathrm{wv0}} V}{R_{\mathrm{wv}} T_0}$$

and

$$\frac{m}{V} = \rho_0 = \frac{p_{\mathrm{a0}}}{R_{\mathrm{a}} T_0} + \frac{p_{\mathrm{wv0}}}{R_{\mathrm{wv}} T_0}$$

Substituting the partial pressure expressions from equations (B.1) and (B.2) into this yields:

$$\rho_0 = \frac{p_0}{R_{\mathrm{a}} T_0} - \frac{\phi_0 p_{\mathrm{s0}}}{T_0} \left(\frac{1}{R_{\mathrm{a}}} - \frac{1}{R_{\mathrm{wv}}} \right) \qquad \text{(B.4)}$$

Finally, substituting the expression for relative humidity in the compressed state from equation (B.3):

$$\rho_0 = \frac{p_0}{R_{\mathrm{a}} T_0} - \phi_1 \left(\frac{p_0}{p_1} \right) \left(\frac{p_{\mathrm{s1}}}{T_0} \right) \left(\frac{1}{R_{\mathrm{a}}} - \frac{1}{R_{\mathrm{wv}}} \right) \qquad \text{(B.5)}$$

B.5 Error analysis

If equation (B.5) gives the density of a mixture at atmospheric conditions, what is the error if an arbitrary value for relative humidity at atmospheric conditions is assumed instead?

The error to be evaluated is defined as follows:

$$\%\,\text{error} = \frac{\text{deviation}}{\text{correct value}}(100) = \frac{\rho_0 - \rho_0'}{\rho_0}(100) = \left[1 - \frac{\rho_0'}{\rho_0} \right](100)$$

From equation (B.4), the density of a mixture for an arbitrary relative humidity at atmospheric conditions will be:

$$\rho_0' = \frac{p_0}{R_{\mathrm{a}} T_0} - \phi_0' \left(\frac{p_{\mathrm{s0}}}{T_0} \right) \left(\frac{1}{R_{\mathrm{a}}} - \frac{1}{R_{\mathrm{wv}}} \right)$$

Substituting this and equation (B.5) into the error formula yields:

$$\%\,\text{error} = \left[1 - \frac{1 - \phi_0' \left(\dfrac{p_{\mathrm{s0}}}{p_0} \right) \left(1 - \dfrac{R_{\mathrm{a}}}{R_{\mathrm{wv}}} \right)}{1 - \phi_1 \left(\dfrac{p_{\mathrm{s1}}}{p_1} \right) \left(1 - \dfrac{R_{\mathrm{a}}}{R_{\mathrm{wv}}} \right)} \right](100) \qquad \text{(B.6)}$$

A series of sample density error calculations is shown in Table B.1, using two cases of arbitrary relative humidity at atmospheric conditions $\phi_0' = 65\ \%$ and $\phi_0' = 0\ \%$. It is assumed the atmospheric pressure is equal to 760 mm Hg.

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Table B.1 — Sample density error calculations

Assumed pressurized state conditions					Calculated at atmospheric pressure of 700 mm Hg and temperature of 20 °C			
p_1 mm H_g abs	p_1 mbar, gauge	T_1 °C	ϕ_1 % RH	p_{s1} mm H_g abs	p_{s0} mm H_g abs	ϕ_0 % RH	% d'erreur at 65 % RH	% d'erreur at 0 % RH
8 500	10 280	20	100	17,5	17,5	8,94	0,488	–0,078
5 500	6 300	20	100	17,5	17,5	13,82	0,446	–0,120
2 300	2 050	20	100	17,5	17,5	33,04	0,279	–0,288
1 000	320	20	100	17,5	17,5	76,00	–0,096	–0,666
8 500	10 280	40	100	55,1	17,5	28,15	0,322	–0,246
5 500	6 300	40	100	55,1	17,5	43,51	0,188	–0,380
2 300	2 050	40	100	55,1	17,5	104,04	–0,343	–0,914
1 000	320	40	100	55,1	17,5	239,29	–1,550	–2,127
8 500	10 280	60	100	149	17,5	76,13	–0,098	–0,667
5 500	6 300	60	100	149	17,5	117,65	–0,463	–1,035
2 300	2 050	60	100	149	17,5	281,34	–1,931	–2,511
1 000	320	60	100	149	17,5	647,09	–5,370	–5,970
8 500	10 280	20	75	17,5	17,5	6,71	0,508	–0,058
5 500	6 300	20	75	17,5	17,5	10,36	0,476	–0,090
2 300	2 050	20	75	17,5	17,5	24,78	0,351	–0,216
1 000	320	20	75	17,5	17,5	57,00	0,070	–0,499
8 500	10 280	40	75	55,1	17,5	21,11	0,383	–0,184
5 500	6 300	40	75	55,1	17,5	32,63	0,283	–0,285
2 300	2 050	40	75	55,1	17,5	78,03	–0,114	–0,684
1 000	320	40	75	55,1	17,5	179,47	–1,012	–1,587
8 500	10 280	60	75	149	17,5	57,10	0,069	–0,500
5 500	6 300	60	75	149	17,5	88,24	–0,204	–0,774
2 300	2 050	60	75	149	17,5	211,01	–1,295	–1,871
1 000	320	60	75	149	17,5	485,31	–3,820	–4,411
8 500	10 280	20	50	17,5	17,5	4,47	0,527	–0,039
5 500	6 300	20	50	17,5	17,5	6,91	0,506	–0,060
2 300	2 050	20	50	17,5	17,5	16,52	0,423	–0,144
1 000	320	20	50	17,5	17,5	38,00	0,236	–0,332
8 500	10 280	40	50	55,1	17,5	14,08	0,444	–0,123
5 500	6 300	40	50	55,1	17,5	21,75	0,377	–0,190
2 300	2 050	40	50	55,1	17,5	52,02	0,114	–0,455
1 000	320	40	50	55,1	17,5	119,65	–0,481	–1,053
8 500	10 280	60	50	149	17,5	38,06	0,235	–0,332
5 500	6 300	60	50	149	17,5	58,83	0,054	–0,515
2 300	2 050	60	50	149	17,5	140,67	–0,667	–1,240
1 000	320	60	50	149	17,5	323,54	–2,316	–2,898
8 500	10 280	20	25	17,5	17,5	2,24	0,547	–0,019
5 500	6 300	20	25	17,5	17,5	3,45	0,536	–0,030
2 300	2 050	20	25	17,5	17,5	8,26	0,494	–0,072
1 000	320	20	25	17,5	17,5	19,00	0,401	–0,166
8 500	10 280	40	25	55,1	17,5	7,04	0,505	–0,061
5 500	6 300	40	25	55,1	17,5	10,88	0,472	–0,095
2 300	2 050	40	25	55,1	17,5	26,01	0,340	–0,227
1 000	320	40	25	55,1	17,5	59,82	0,045	–0,524
8 500	10 280	60	25	149	17,5	19,03	0,401	–0,166
5 500	6 300	60	25	149	17,5	29,41	0,311	–0,257
2 300	2 050	60	25	149	17,5	70,34	–0,047	–0,616
1 000	320	60	25	149	17,5	161,77	–0,854	–1,428
8 500	10 280	20	10	17,5	17,5	0,89	0,558	–0,008
5 500	6 300	20	10	17,5	17,5	1,38	0,554	–0,012
2 300	2,05	20	10	17,5	17,5	3,30	0,537	–0,029
1 000	320	20	10	17,5	17,5	7,60	0,500	–0,066
8 500	10 280	40	10	55,1	17,5	2,82	0,541	–0,025
5 500	6 300	40	10	55,1	17,5	4,35	0,528	–0,038
2 300	2 050	40	10	55,1	17,5	10,40	0,476	–0,091
1 000	320	40	10	55,1	17,5	23,93	0,358	–0,209
8 500	10 280	60	10	149	17,5	7,61	0,500	–0,066
5 500	6 300	60	10	149	17,5	11,77	0,464	–0,103
2 300	2 050	60	10	149	17,5	28,13	0,322	–0,246
1 000	320	60	10	149	17,5	64,71	0,003	–0,567

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B.6 Observations

This analysis describes the error resulting when air in a compressed state is equated to atmospheric conditions and an arbitrary value is assumed for its relative humidity. The last two columns of Table B.1 describe the error caused by this effect, at the two sets of conditions defined in this International Standard.

Each group of four rows in Table B.1 shows a different temperature or relative humidity in the compressed state. The pressure varies from high to low in each group of four rows.

The shaded cells in Table B.1 highlight conditions in which the relative humidity at atmospheric conditions has exceeded 100 %, which would result in condensation. This demonstrates limitations to the concept that water vapour in air at the compressed state may be equated to the atmospheric state.

A positive error indicates that the arbitrary change results in a lower density. A negative error yields a higher density.

B.7 Conclusion

In general, condensation will occur when compressed air with a high relative humidity and high temperature is expanded to atmospheric conditions. The equations are then limited in their applicability in these conditions.

For equivalent state calculations, where air is not actually expanding, the density error is minor for the two cases of arbitrary relative humidity. It is cautioned, however, that these are only sample calculations and may differ from actual applications.

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