A4 3 Physical principles

3.1 Dewpoint [°C_{td}]

Pressure dewpoint [°Ctd] is the temperature to which compressed air can be cooled without condensate forming. The dewpoint is dependent on the process pressure. When the pressure drops, the dewpoint also sinks.

In systems under pressure, the pressure dewpoint is always relevant, but not the atmospheric dewpoint. The difference between these physical parameters is explained in the following pages.

3.2 Atmospheric dewpoint [°CtdA]

Atmospheric dewpoint [°Ctd] is the temperature to which atmospheric air (approx. 1 bar absolute) can be cooled without water condensing.

3.2.1 Difference between pressure dewpoint and atmospheric dewpoint

Pressure dewpoint or atmospheric dewpoint?

Atmospheric air is able to store more water vapour than compressed air. If compressed air is cooled, it already reaches its dewpoint at higher temperatures ("dewpoint" in °Ctd or°Ftd), while atmospheric air can be cooled further before condensate is first precipitated (atmospheric dewpoint, in °Ctd or °Ftd).

For the monitoring of compressed air systems, only the dewpoint is relevant, as it indicates how far away the "danger threshold" =dewpoint) is. Since some users wish for the data in atm. dewpoint in spite of this, the testo 6740 allows the choice of the outputs dewpoint and atm. dewpoint (for the latter the process pressure is entered in the operating menu).

We consider a cube with 1 m^3 of air at 20 °C with 20 % relative humidity. This corresponds to a content of 3 g of water vapour, whereas air can hold a mximum of 15 g/m^3 at 20 °C (temperature-dependent saturation humidity).

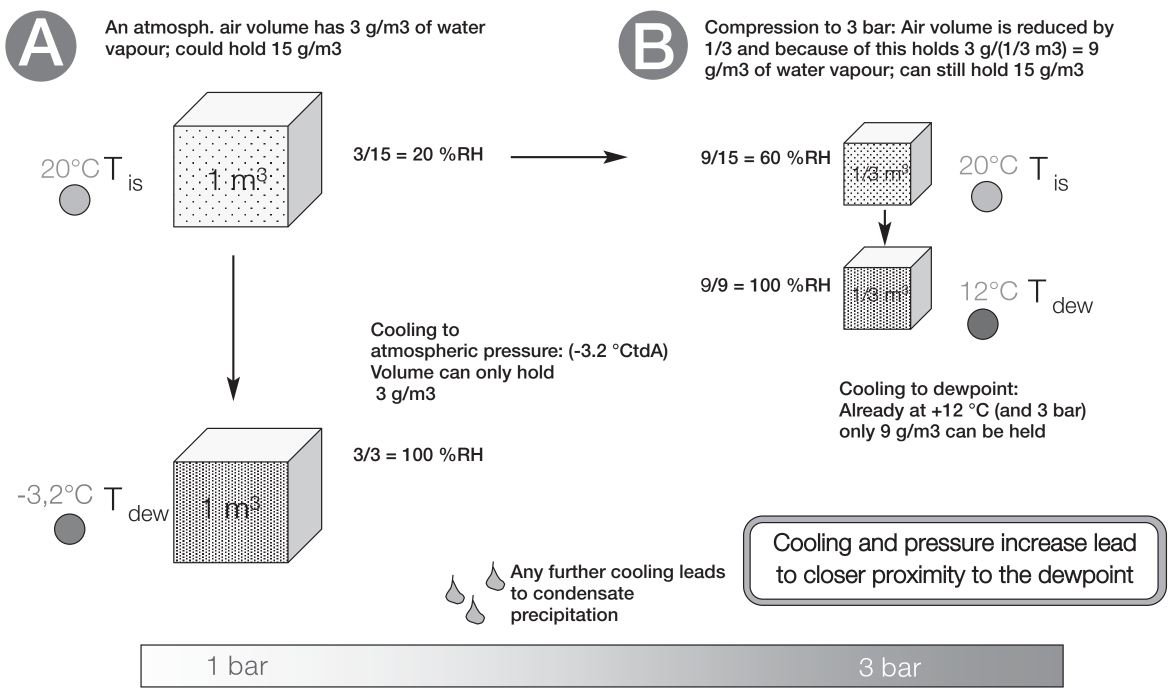
Case A (atm. dewpoint):
The pressure remains constant at 1 bar and the cube is cooled down to the dewpoint temperature. 3 g of water vapour continue to be contained per cubic metre. With cooling, however, the ability of the air to store humidity is reduced. At -3.2 °C, only exactly the 3 g contained can be stored.

The air cube reaches the dewpoint and begins to condense. This dewpoint is called atmospheric dewpoint (-3.2 °Ctd), because it occurs at atmospheric pressure.

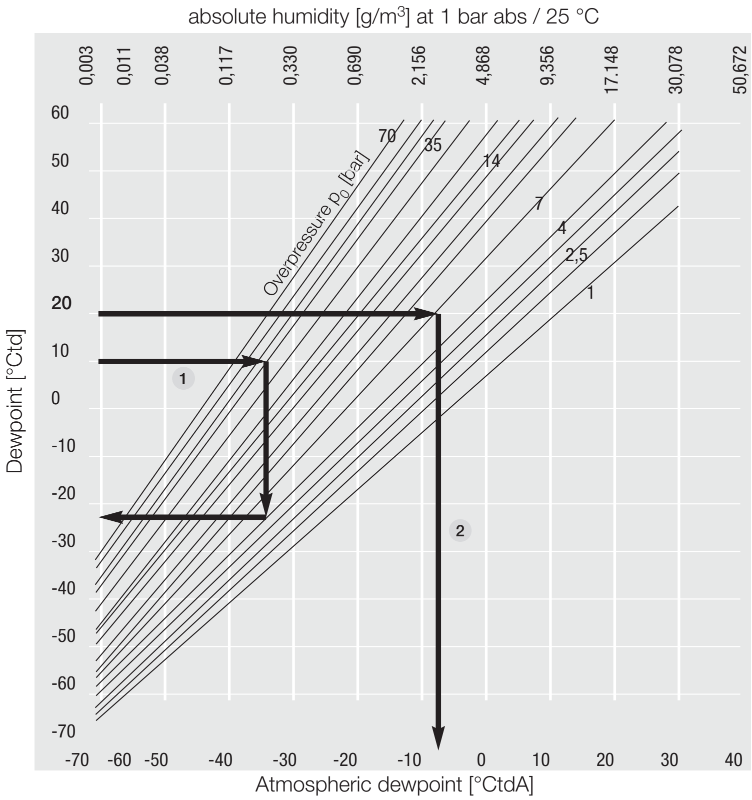
Case B (dewpoint):
The pressure is raised to 3 bar, causing the volume of the cube to shrink to 1/3 of the original size. The air cube still contains the ware vapour mass of 3 g even after being compressed (humidity has been neither added nor extracted), however the absolute humidty is now 3 g/(1/3 m^3) = 9 g/m^3 owing to the reduction in volume to 1/3 m^3. As the temperature is still 20 °C and the saturation (maximum possible humidity storage) is purely temperature-dependent, 15 g/m^3 can still be held. The relative humidity is thus 9/15 = 60 %RH, i.e. the compression of the air from 1 to 3 bar has lead to an increase in relative humidity by a factor of 3.

If this compressed cube is now cooled, it already reaches the dewpoint at 12 °Ctd, as the air reaches its saturation of 9 g/m^3 here (=max. possible humidity storage).

This clearly shows: Raising pressure raises the dewpoint. At constant process temperatures the safety margin (Temperature distance from the dewpoint) is thus smaller!



3.2.2 Conversion pressure dewpoint - atmospheric dewpoint



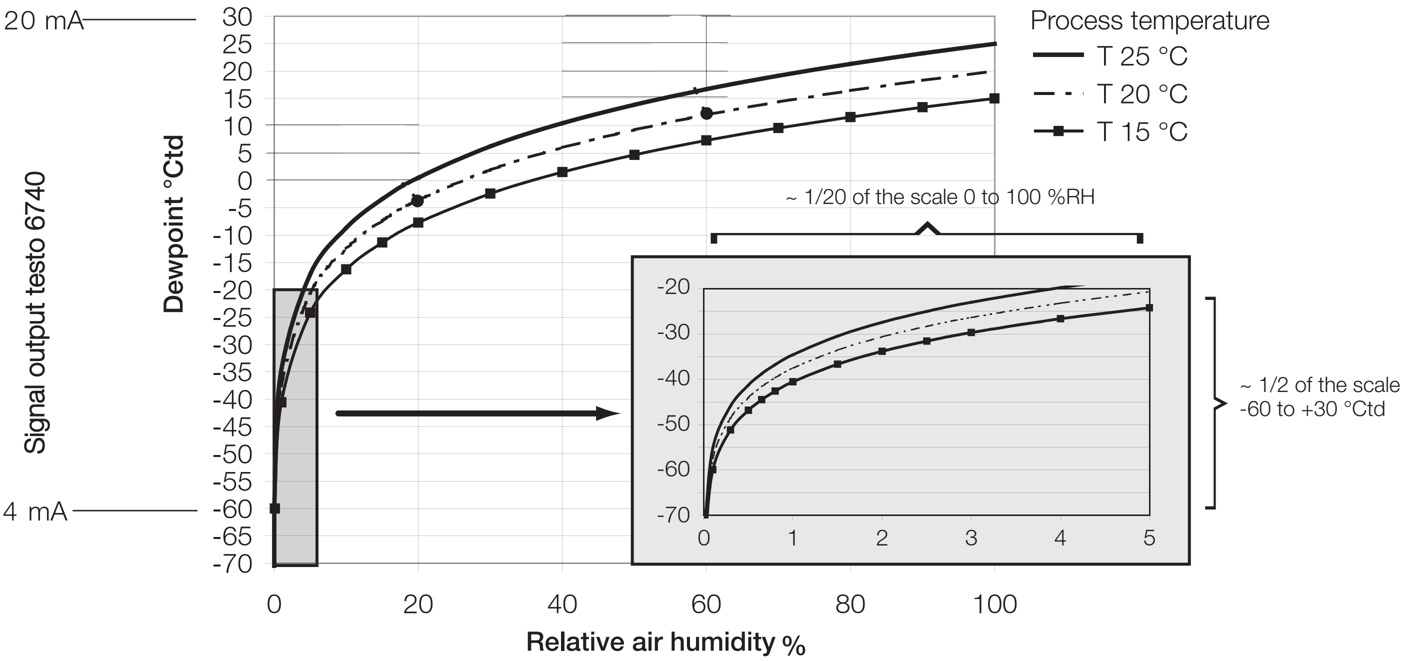
① Compressed air (35 bar) is depressurized to 4 bar. This causes the dewpoint to sink from 10 °Ctd to -33 °Ctd

② Compressed air (7 bar) has a pressure dewpoint of 20 °Ctd. This corresponds to an atm. dewpoint of -8 °CtdA.

3.2.3 Dewpoint and relative humidity

The dewpoint is the temperature at which water condenses out of compressed air. It is dependent on the relative humidity and the process temperature (see diagram below). The lower the relative humidity is the lower the dewpoint (at constant pressure and process temperature).

As the following diagram shows, the humidity parameter "dewpoint" provides a considerably better resolution than relative humidity in the low humidity range (<2 %RH, but especially <1 %RH). While the trace humidity range -60 to -20 °Ctd comprises approx. half of the compressed air scale (-60 to +30 °Ctd), 0 to 5 %RH correspond to only a twentieth of the scale 0 to 100 %RH.



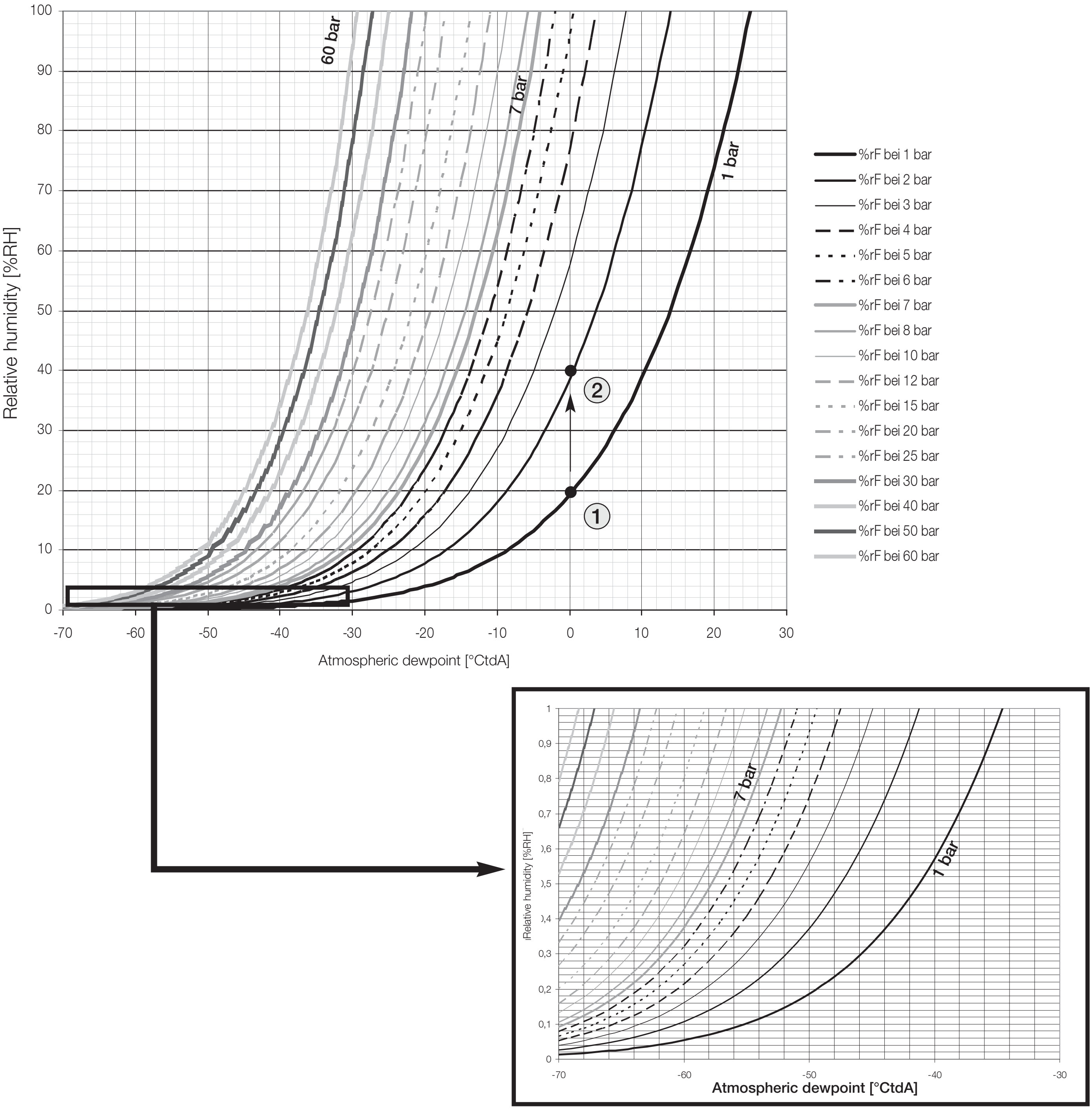
3.2.4 Relative humidity and atmospheric dewpoint

As can be seen in the following diagram, at a constant process temperature (25 °C) the relative humidity increases with increasing pressure and constant atmospheric dewpoint.

The pressure increase has no influence on the atmospheric dewpoint! Only the pressure dewpoint is changed (cf. chapter 1.12.2.1)

Example: The air with atmospheric dewpoint (0 °Ctd) is compressed from 1 to 2 bar. This doubles the relative humidity from 20 %RH ① to 40 %RH ②.

Relationship of atmospheric dewpoint to relative humidity at 25 °C process temperature



A4 3 Physical principles

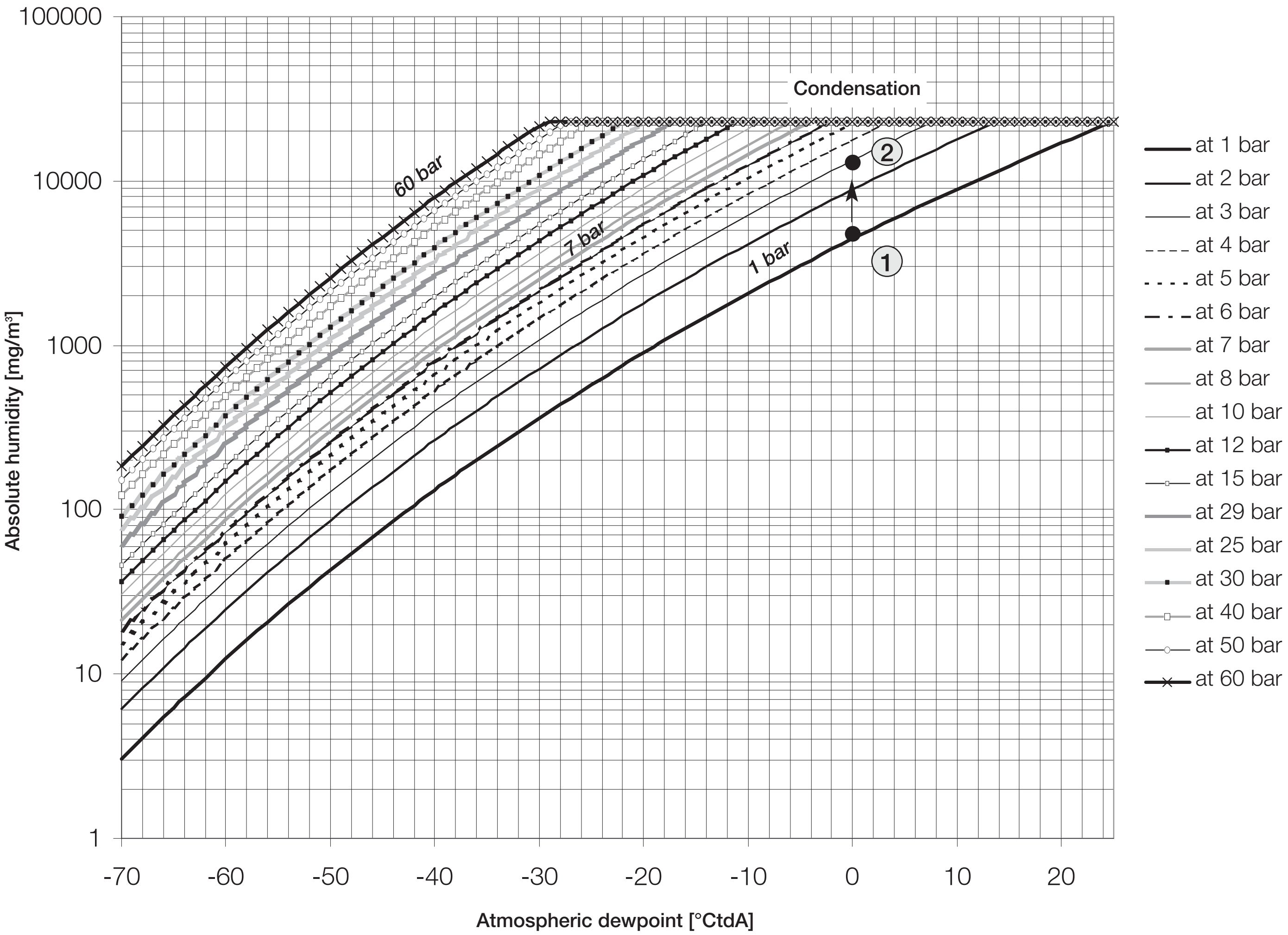
3.2.5 Absolute humidity and atmospheric dewpoint

As can be seen in the following diagram, at constant process temperature (25 °C), the absolute humidity increases with increasing pressure and constant atmospheric dewpoint, until water condenses at 23050 mg/m³ at 25 °C (corresponds to 100 %RH).

The pressure increase has no influence on the atmospheric dewpoint! Only the pressure dewpoint changes (cf. Chapter 1.12.2.1)

Example: The air with atmospheric dewpoint (0 °Ctd) is compressed from 1 to 3 bar. This triples the absolute pressure from 4440 mg/m³ ① to 13320 mg/m³ ②.

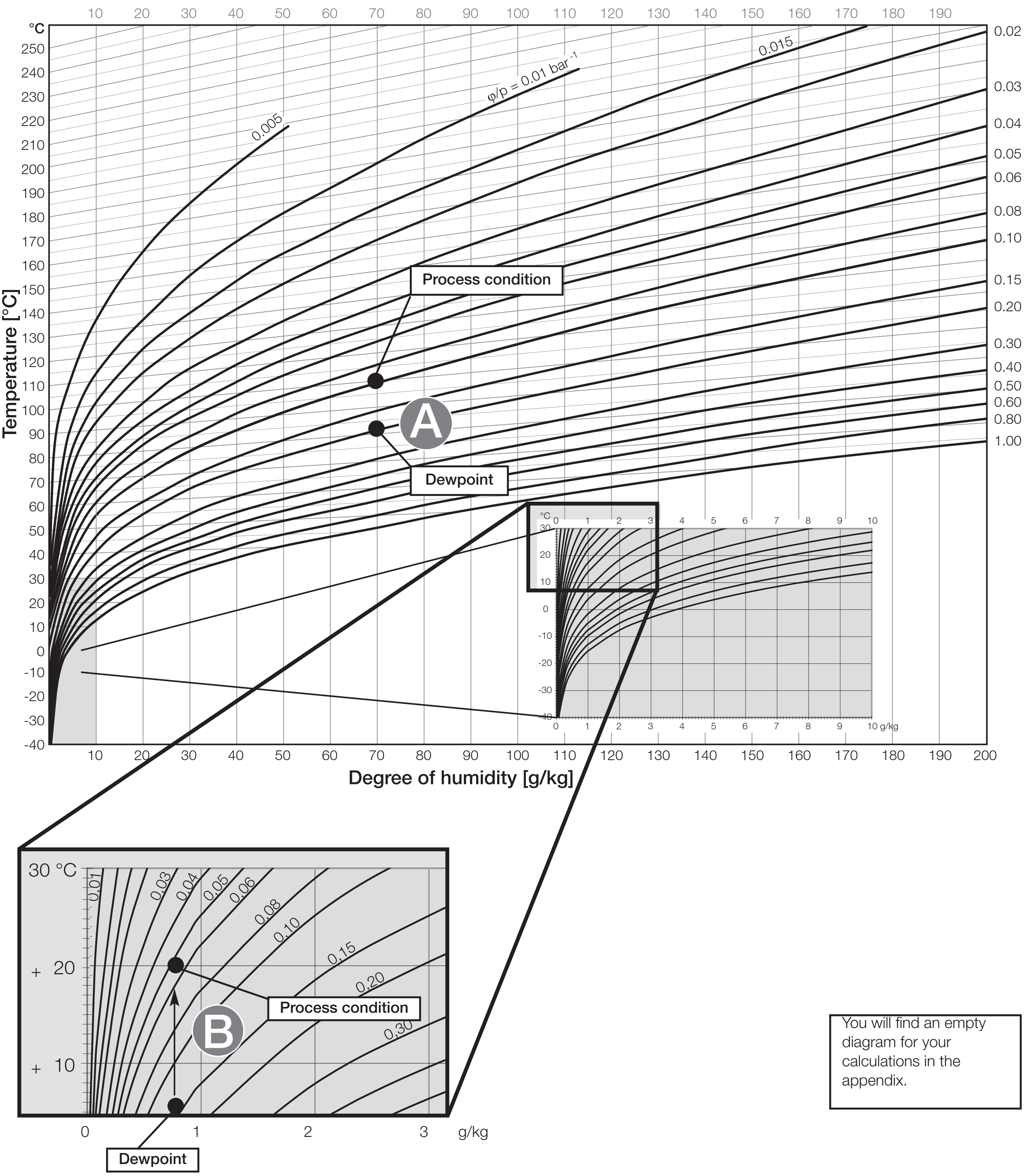
Relationship of atmospheric dewpoint to absolute humidity at 25 °C process temperature



3.3 Psychrometric chart (Mollier diagram) for pressurized systems

Conventional psychrometric charts are only valid at one pressure level, usually at atmospheric pressure (application in the area of air conditioning technology, cf. “Stationary Measurement Technology for Humidity, Differential Pressure and Temperature, chapter 1.13.1”). The psychrometric chart shown here allows various humidity parameters (dewpoint [°Ctd], rel. humidity [%RH] and degree of humidity [g/kg] as well as the temperature [°C]) to be placed in relationship to each other, also under non-atmospheric pressure.

Relative air humidity under pressure conditions $\left[\frac{\varphi\left[\frac{\%RH}{100\%}\right]}{P\,[\mathrm{bar}]}\right]$ e.g. 40% / 5 bar: $\frac{40\%}{100\%} \cdot \frac{1}{5\ \mathrm{bar}} = 0{,}08\ \mathrm{bar}^{-1}$



You will find an empty diagram for your calculations in the appendix.

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3.3.1 (A) Example for the use of the psychrometric chart for determining the pressure dewpoint

A pressurized system has the parameters 100 °C, 5 bar and 50 %RH. Which dewpoint does it have?

➔ Point ($100°C \left| \frac{50\%RH}{100\% \bullet 5bar} \right.$) = $(100°C \left| \frac{0.1}{bar} \right.)$ go vertically down to the dewpoint curve for P = 5 bar, which is derived as follows:

➔ Derivation and reading of the dewpoint curve für P=5 bar:

$$\frac{100\%RH}{100\%RH} \times \frac{1}{5bar} = 0.2\,bar^{-1}$$

➔ Dewpoint = 81.71 °Ctd (can be read on left axis)

3.3.2 (B) Example for the use of the psychrometric chart for determining the relative humidity behind the refrigeration dryer

A pressurized refrigeration dryer has the parameters 5°Ctd, 20°C und 7 bar. How much %RH does this correspond to?

1 Derivation and reading of the dewpoint curve for P= 7 bar: (here there are 100 %RH)

$$\frac{100\%RH}{100\%RH} \times \frac{1}{7bar} = 0.14\,bar^{-1}$$

The point (5 °Ctd / 0.78 g/kg) is situated at 5 °Ctd

2 Read the conversion factor for determining the relative humidity: Point (5 °Ctd|0.78 g/kg) ; go vertically up to 20 °C.The point (20 °C/0.78 g/kg), through which the curve 0.053 bar^{-1} runs, is situated here.

From the formula $\frac{U[\%]}{100\%} \times \frac{1}{P[bar]} = 0.053\,bar^{-1}$

follows with P=7 bar: $\frac{U[\%]}{100\%} \times \frac{1}{7bar} = 0.053\,bar^{-1}$

solve acc. to U: $U[\%RH] = 7 \times 0.053 \times 100\%RH = 37.1\%RH$

3.4 Dewpoint calculation [°C$_{td}$]

The ability of air or gases to hold water decreases with sinking temperatures. The dewpoint is the temperature [°Ctd], at which water condenses.

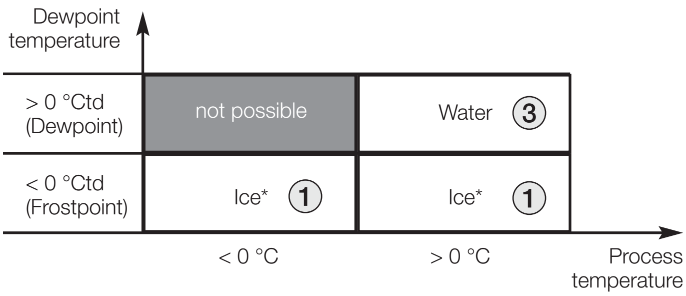
$$T_d = \frac{-\ln\left(\frac{p_w}{C_1}\right)\cdot C_3}{\ln\left(\frac{p_w}{C_1}\right) - C_2}$$

p_w = Water vapour partial press. [mbar]
T_d = Dewpoint temperature [°Ctd]
C1, C2, C3 see table
ln = natural logarithm

Coefficients according to Magnus(DIN 50010)

Phase	Process temperature T [°C]	C1 [mbar]	C2	C3 [°C]
① Ice	-50.9 to 0	6.10714	22.44294	272.44
② Water	-50.9 to 0	6.10780	17.84362	245.425
③ Water	0.0 to 100	6.10780	17.08085	234.175

Case difference in dewpoint/frostpoint calculation



*Attention in measurement comparisons: some measuring instrument manufacturers use the water coefficients ② here

If the dewpoint temperature is above 0 °Ctd, the dewpoint temperature is generally given; however if it is under 0 °Ctd, the frostpoint temperature is given.

For dewpoint temperatures, the measurement values of the testo 6740 and of a dewpoint mirror hygrometer are concurrent under observation of measurement tolerances.

In rare cases, differences between the testo 6740 and a dewpoint mirror hygrometer can occur at frostpoint temperatures between -35 °C to 0 °C. This happens when, at frostpoint temperatures <0 °C, supercooled/subcooled water is formed on the surface of the dewpoint mirror hygrometer instead of the expected ice. The dewpoint mirror measures the frostpoint (according to the coefficients ② see above.), while the testo 6740 measues the frostpoint according to the coefficients ①. In measurement comparisons, a conversion must be made according to the above formula.

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3.5 Proportional volume [ppm_V]

Parts per million by volume describe the relationship of the water vapour partial pressure to the total pressure of the dry gas (without water vapour partial pressure)

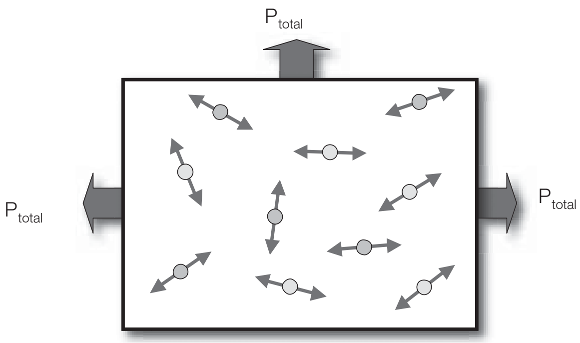
$$ppm_v = \frac{\text{Water vapour partial pressure}}{\text{(Total gas pressure - water vapour partial pressure)}} \times 10^6$$

Dalton's Law (the law of partial pressures) states that the sum of all partial pressures P_i is equal to the total pressure of the gas mixture P_{total}

Humid air is composed of dry air and water vapour. This results in:

$$P_{total} = P_t + P_W$$

P_{total} = Total pressure [mbar]
P_t = Pressure of the dry air [mbar]
P_W= Water vapour partial pressure [mbar]



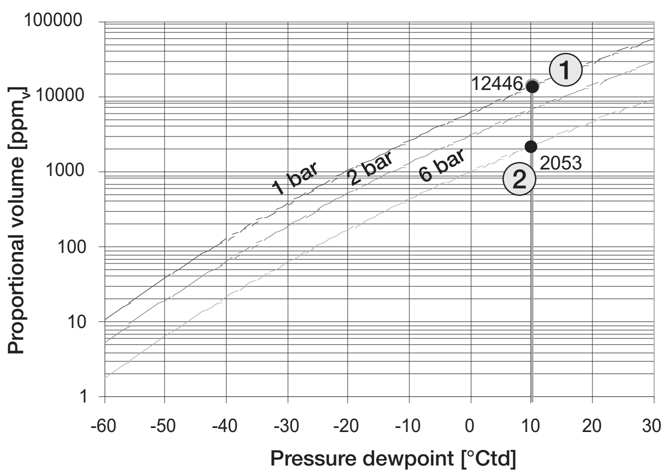
$$P_{total} = P_{air} + P_{water}$$

= water vapour partial pressure

As the testo 6740 measures the (pressure-dependent) dewpoint, for the output of the (non-pressure-dependent) ppm-value the absolute pressure is entered in the menu ProG as compensation (cf. chap. 1.2.5); the microprocessor calculates the ppm_V-value on this basis.

Example:
If a pressure of 6 bar at 10 °Ctd exists, the instrument measures 12.446 ppm_V ①. In order that the appropriate value 2053 ppm_V ② is displayed, the absolute pressure (6 bar) must be entered in the Menü ProG (cf. chap. 1.2.5).

Proportional volume to dewpoint (= f(P_{abs}))



3.6 Absolute humidity [g/m³]

The absolute humidity [g/m³] indicates how many grams of water are present in one cubic metre of dry air or dry gas.

Since we are dealing with very small absolute humidty values in trace humidity applications (cf. chapter 1.12.2.1), the testo 6740 gives the absolute humidity in mg/m³ .

$$\text{Absolute humidity} = \frac{\text{Water weight}}{\text{Gas volume}} \quad [g/m^3]$$

3.7 Pressure dependency of humidity parameters

The testo humidity sensor measures the relative humidity %RH directly (without the "knowledge"/input of the pressure). As this parameter is in itself pressure-dependent, all pressure-dependent parameters (°Ctd, g/m³,%RH) are also calculated correctly without pressure input. For the pressure-independent humidity parameters (ppm, °Ctd = atmospheric dewpoint temperature), however, the pressure must be corrected/eliminated by entering the absolute pressure (in the operating menu/ scaling adapter) (see illustration and cf. chapter 1.12.2.2 and 1.12.5).

3.8 Reaction of humidity parameters to changes of pressure and/or temperature

The following table shows the reaction of humidity parameters to changes of pressure and/or temperature. The atmospheric dewpoint and the water content are independent of pressure and temperature.

	Pressure falling ▼	Pressure constant ●	Pressure rising ▲
Temperature rising ▲	● Atm. dewpoint ▼ Pressure dewpoint ▼ Rel. humidity ▼ Absolute humidity ● Degree of humidity ▲ Saturated vapour pressure ▼ Water vapour partial pressure ● Water content	● Atm. dewpoint ● Pressure dewpoint ▼ Rel. humidity ▼ Absolute humidity ● Degree of humidity ▲ Saturated vapour pressure ● Water vapour partial pressure ● Water content	●[2] Atm. dewpoint ▲[2] Pressure dewpoint ○[2] Rel. humidity ○[2] Absolute humidity ●[2] Degree of humidity ▲[2] Saturated vapour pressure ▲[2] Water vapour partial pressure ●[2] Water content
Temperature constant ●	● Atm. dewpoint ▼ Pressure dewpoint ▼ Rel. humidity ▼ Absolute humidity ● Degree of humidity ● Saturated vapour pressure ▼ Water vapour partial pressure ● Water content	All humidity parameters unchanged	●[2] Atm. dewpoint ▲[2] Pressure dewpoint ▲[2] Rel. humidity ▲[2] Absolute humidity ●[2] Degree of humidity ●[2] Saturated vapour pressure ▲[2] Water vapour partial pressure ●[2] Water content
Temperature falling ▼	● Atm. dewpoint ▼[1] Pressure dewpoint ○[1] Rel. humidity ○[1] Absolute humidity ●[1] Degree of humidity ▼[1] Saturated vapour pressure ▼[1] Water vapour partial pressure ● Water content	● Atm. dewpoint ●[1] Pressure dewpoint ▲[1] Rel. humidity ▲[1] Absolute humidity ●[1] Degree of humidity ▼[1] Saturated vapour pressure ●[1] Water vapour partial pressure ● Water content	●[2] Atm. dewpoint ▲[1,2] Pressure dewpoint ▲[1,2] Rel. humidity ▲[1,2] Absolute humidity ●[1,2] Degree of humidity ▼[1,2] Saturated vapour pressure ▲[1,2] Water vapour partial pressure ●[2] Water content

- ▼ **falls**
- ● **remains constant**
- ▲ **rises**
- ○ **generalization not possible (please calculate individually)**

Units:
Atm. dewpoint [°CtdA]
Dewpoint [°Ctd]
Relative humidity [%RH]
Absolute humidity [g/m³]
Degree of humidity [g/kg]
Saturated pressure [mbar]
Water vapour partial pressure [mbar]
Water content [V-ppm]

[1] As soon as the dewpoint is reached by cooling, water oondenses, and thus the humidity parameters sink with further cooling - apart from the relative humidity, which remains constant after condensation is formed.

[2] As soon as the dewpoint is reached by compressing the air, water condenses (cf. chapter 1.12.2) and the humidity parameters remain constant with rising pressure - apart from the degree of humidity, this sinks from the moment condensation is formed, as condensate mass is withdrawn.

3.9 Temperature and pressure dependency of humidity parameters

Humidity parameter	Pressure-dependent	Temperature-dependent
Water content/proportional volume atmospheric dewpoint degree of humidity	NO	NO
Saturated vapour pressure	NO	YES
Pressure dewpoint	YES	NO
Water vapour partial pressure relative humidity absolute humidity	YES	YES

Relationship relative humidity to ppm_v at 25 °C