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HUMID AIR

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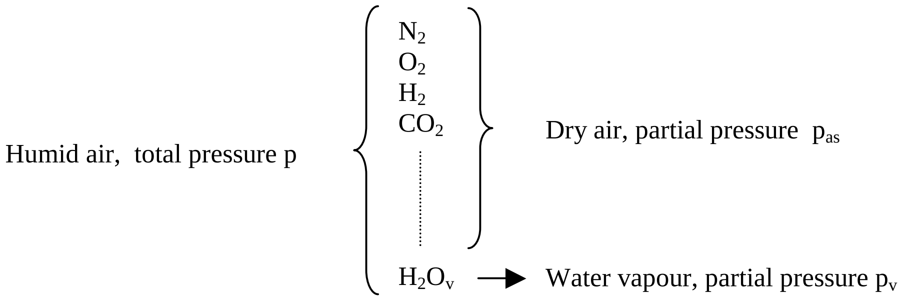
1 INTRODUCTION

The main components of air are oxygen and nitrogen but air also contains other gases and particularly water vapour:

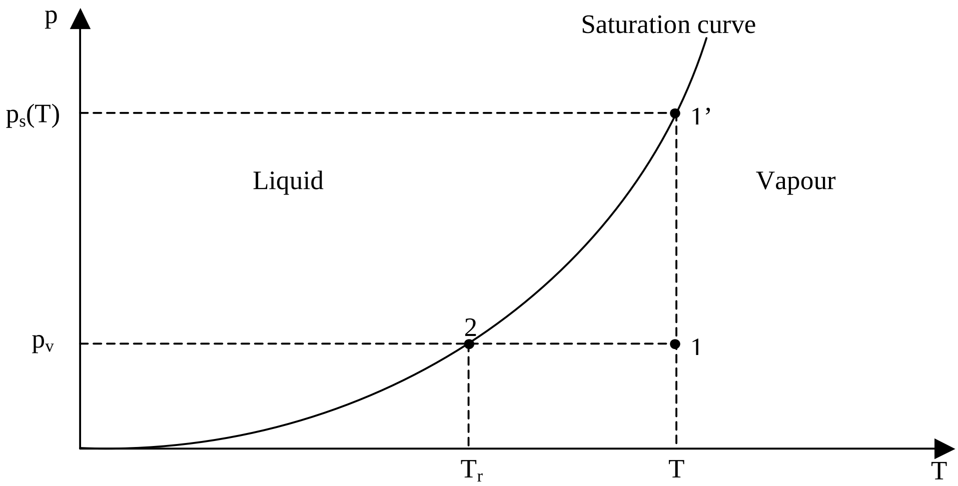


The water vapour partial pressure p_v in the atmosphere is never null whatever the climate and the season are, even if its value may strongly vary. As an example, one can consider the following mean values observed in Ouagadougou (Sahelian climate): p_v = 4 mmHg in February and p_v = 20 mmHg in April.

2 HUMID AIR PARAMETERS

2.1 Temperatures and humidities

Let us plot in a diagram (p,T) the point 1 representing the water vapour with a partial pressure p_v contained in air with a temperature T and a total pressure p:



$p_s(T)$ is the saturation pressure (at the equilibrium liquid-vapour) of the water vapour at temperature T. One can find in Appendix 1 a table giving water physical properties. One can also use the ***Dupré relationship*** useful between –50°C and +200°C to calculate $p_s(T)$:

$$p_s(T) = \exp\left[46.784 - \frac{6435}{T + 273.15} - 3.868 \ln(T + 273.15)\right] \qquad (2.1)$$

With: T Temperature (°C)
$p_s(T)$ Saturation pressure (mmHg).

The water contained in the air is gaseous (water vapour) if $p_v \le p_s(T)$, one can then define the ***relative humidity HR*** of the air by the following relationship:

$$(0 \le HR \le 100\%) \qquad HR = \frac{p_v}{p_s(T)} \times 100 \qquad (2.2)$$

If air is cooled under a constant pressure, its relative humidity increases until it reaches the value 100% (point 2 on the saturation curve). A vapour-liquid equilibrium occurs and the first drops of condensed water appear so that the temperature at point 2 is called the ***dew point temperature T_r***. It is defined by:

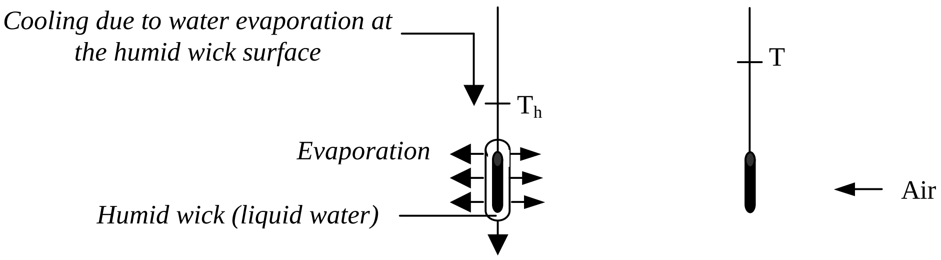
$$p_v = p_s(T_r) \qquad (2.3)$$

Air humidity is also defined by another characteristic parameter that is the ***absolute humidity x*** ($kg_{water}.kg_{da}^{-1}$) defined as the mass of the water vapour contained in the air for each dry air kg:

$$x = \frac{m_v}{m_{as}} \qquad (2.4)$$

Where m_v and m_{as} are the masses of water vapour and dry air contained in the same volume V of humid air, so that (1+x) kg of humid air contains 1 kg of dry air and x kg of water vapour.

One defined a last characteristic parameter that is the ***wet bulb temperature T_h*** of the air: it is the equilibrium temperature of a water mass evaporating in the air in the case where the evaporation heat is provided only by the air.



The difference ($T - T_h$) is representative of the air relative humidity HR since:

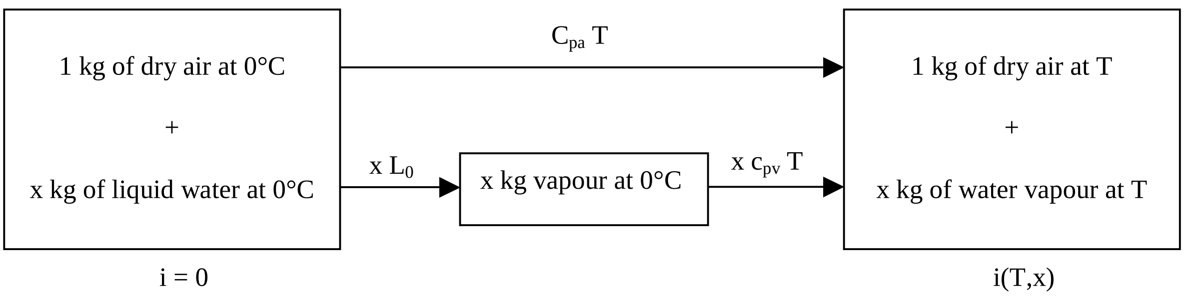
- It is null if the air is saturated with water vapour corresponding to HR = 100%: no possible evaporation.
- It increases with the difference [$p_s(T) - p_v$] that is the driving term of the mass transfer so it decreases when $HR = \frac{p_v}{p_s(T)}$ increases.

2.2 Specific enthalpy

It is the global heat contained in a mass (1+x) of humid air, the enthalpy being null for dry air with liquid water at 0°C.

The ***specific enthalpy i*** is expressed as:

$$i(T,x) = C_{pa}\, T + x\,(L_0 + c_{pv}\, T) \qquad (2.5)$$



Where:	c_{pa}	Specific heat of dry air	$c_{pa} = 1006\ J.kg^{-1}.°C^{-1}$
	c_{pv}	Specific heat of water vapour	$c_{pv} = 1840\ J.kg^{-1}.°C^{-1}$
	L_0	Vaporisation heat of water at 0°C	$L_0 = 2501\ kJ.kg^{-1}$.

2.3 Relationships between the air characteristic parameters

2.3.1 Relationship between p_v and x

Let us consider (1+x) kg of humid air with an absolute humidity x, a temperature T and a water vapour partial pressure p_v. The total pressure is P and the occupied volume is V.

The perfect gas law leads to:

$$\begin{cases} p_{as}\ V = 1\,\dfrac{R}{M_{as}}\,T \\ p_v\ V = x\,\dfrac{R}{M_v}\,T \end{cases} \longrightarrow \begin{cases} M_{as}\ p_{as} = \dfrac{R\,T}{V} \\ \dfrac{M_v\ p_v}{x} = \dfrac{R\,T}{V} \end{cases}$$

So: $x = \dfrac{M_v\ p_v}{M_{as}\ p_{as}}$ or: $p_{as} = p - p_v$

One obtains:

$$x = \delta\,\frac{p_v}{p - p_v} \qquad (2.6)$$

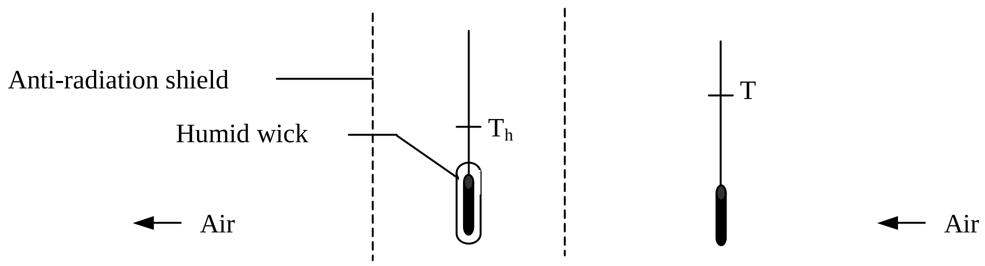
Where $\delta = \dfrac{M_v}{M_{as}} = 0.622$

It can also be written:

$$p_v = \frac{x\,p}{\delta + x} \qquad (2.7)$$

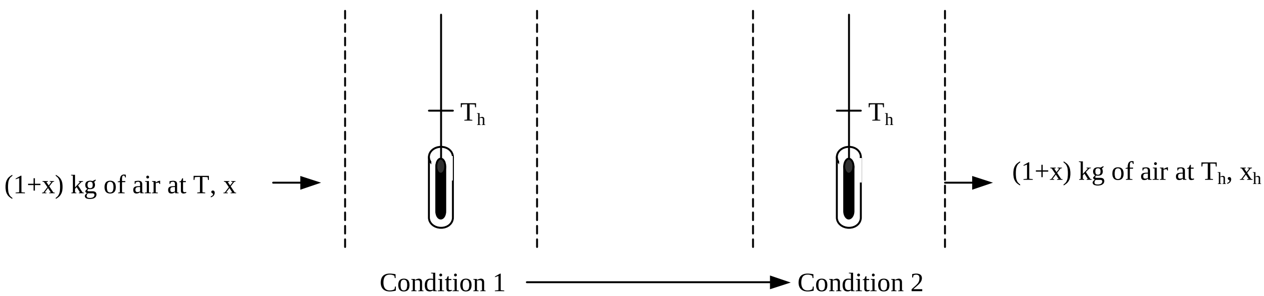
2.3.2 Relationship between p_v, T and T_h

Let us consider a thermometer, which bulb is recovered with a wick (tissue, cotton,…) imbibed with liquid water and placed in an air flow. The thermometer is protected from external heat transfer by an anti-radiation shield so that it exchanges heat only with air:



By definition, the temperature indicated by the thermometer, that is the temperature of the mass of liquid water surrounding the bulb in equilibrium with air, is the air wet bulb temperature T_h.

Let us apply an energy balance on the system liquid water+air (saturated after the exchange) at the neighbourhood of the humid wick:



There is no external energy supply so the enthalpy of the system is constant and: $H_1 = H_2$.

$$H_1 = m_l\ c_{pl}\ T_h + \left(c_{pa} + x\ c_{pv}\right) T + x\ L_0$$

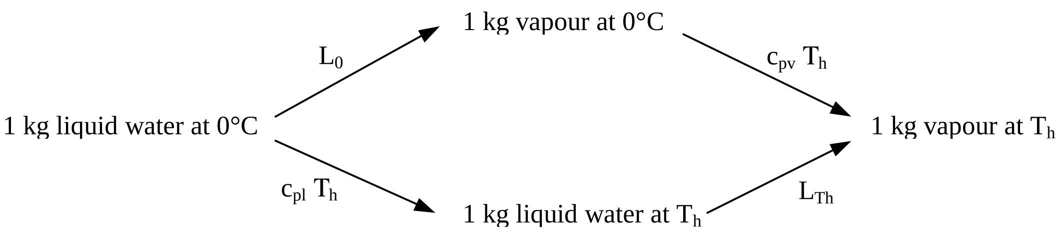
$$H_2 = \left[m_l - \left(x_h - x\right)\right] c_{pl}\ T_h + \left(c_{pa} + x_h\ c_{pv}\right) T_h + x_h\ L_0$$

$$H_1 = H_2 \quad \rightarrow \quad \left(x_h - x\right) L_0 - \left(x_h - x\right) c_{pl}\ T_h + c_{pa}\ \left(T_h - T\right) + x_h\ c_{pv}\ T_h - x\ c_{pv}\ T = 0$$

$$H_1 = H_2 \quad \rightarrow \quad \left(x_h - x\right)\left(L_0 - c_{pl}\ T_h\right) + c_{pa}\ \left(T_h - T\right) + x_h\ c_{pv}\ T_h - x\ c_{pv}\ T + x\ c_{pv}\ T_h - x\ c_{pv}\ T_h = 0$$

$$H_1 = H_2 \quad \rightarrow \quad \left(x_h - x\right)\left[L_0 + \left(c_{pv} - c_{pl}\right) T_h\right] + \left(c_{pa} + x\ c_{pv}\right)\left(T - T_h\right) = 0$$

Or : $L_{Th} = L_0 + \left(c_{pv} - c_{pl}\right) T_h$:



So : $H_1 = H_2 \quad \rightarrow \quad \left(x_h - x\right) L_{Th} + \left(c_{pa} + x\ c_{pv}\right)\left(T_h - T\right) = 0$

It may be written:

$$\boxed{\left(x_h - x\right) L_{Th} = \left(c_{pa} + x\ c_{pv}\right)\left(T - T_h\right)} \qquad (2.8)$$

The value of L_{Th} may be calculated with an error less than 1% with the following relationship valid between 0°C and 180°C:

$$\boxed{L_T = 2501 - 2.65 T} \qquad (2.9)$$

Where: L_T Vaporisation heat of water at temperature T ($kJ.kg^{-1}$).
T Temperature (°C)

It is possible to introduce the water vapour pressure p_v, that can be done by a transformation of relation (2.8) using the relationship previously established:

$x = \delta \dfrac{p_v}{p - p_v}$ and $x_h = \delta \dfrac{p_s\left(T_h\right)}{p - p_s\left(T_h\right)}$ (Saturated air after contact with the wet bulb)

One obtains:

$$\boxed{\delta\left[\frac{p_s\left(T_h\right)}{p - p_s\left(T_h\right)} - \frac{p_v}{p - p_v}\right] L_{Th} = \left[c_{pa} + \delta \frac{p}{p - p_v} c_{pv}\right]\left(T - T_h\right)} \qquad (2.10)$$

So: $$\frac{p_v}{p - p_v} = \frac{\delta \dfrac{p_s\left(T_h\right)}{p - p_s\left(T_h\right)} L_{Th} - c_{pa}\left(T - T_h\right)}{L_{Th} + c_{pv}\left(T - T_h\right)}$$

Remarking that: $c_{pv}\ \left(T - T_h\right) << L_{Th}$ and that: $p - p_v \approx p - p_s\left(T_h\right)$

One finally founds:

$$\boxed{p_v = p_s\left(T_h\right) - \frac{c_{pa}\ \left(T - T_h\right)\left[p - p_s\left(T_h\right)\right]}{\delta\ L_{Th}}} \qquad (2.11)$$

This relationship is sometimes written as: $p_v = p_s(T_h) - A\,(T - T_h)$

Where $A = \dfrac{c_{pa}\;[p - p_s(T_h)]}{\delta\, L_{Th}}$ is called the psychrometric constant.

2.3.3 Density

Let us consider (1+x) kg of humid air with an absolute humidity x, a temperature T and a water vapour partial pressure p_v. The total pressure is P and the occupied volume is V.

The density of the air is: $\rho = \dfrac{1+x}{V}$

Applying the perfect gas law to dry air and water vapour one obtains:

$$\begin{cases} p_{as}\, V = 1\,\dfrac{R}{M_{as}}\;T \\ p_v\, V = x\,\dfrac{R}{M_v}\;T \end{cases} \longrightarrow \begin{cases} 1 = \dfrac{p_{as}\; M_{as}\; V}{R\,T} \\ x = \dfrac{p_v\; M_v\; V}{R\,T} \end{cases}$$

The addition of these two relations gives: $1 + x = \dfrac{1}{R\,T}\left(M_{as}\; p_{as} + M_v\; p_v\right) = \dfrac{M_{as}}{R\,T}\left(p_{as} + \dfrac{M_v}{M_{as}}\; p_v\right)$

But: $p_{as} = p - p_v$ and: $\dfrac{M_v}{M_{as}} = \delta$ so: $\rho = \dfrac{M_{as}}{R\,T}\left(p - p_v + \delta\, p_v\right)$

For dry air in reference conditions, that is: p_0 = 101 325 Pa, T_0 = 273.15 K = 0°C, one can write:

$p_0 = \rho_0\,\dfrac{R}{M_{as}}\,T_0$ so: $\dfrac{M_as}{R} = \dfrac{\rho_0\;T_0}{p_0}$

And then finally:

$$\rho = \rho_0\,\frac{T_0}{T}\,\frac{p - (1-\delta)\,p_v}{p_0} \qquad (2.12)$$

With: p_0 = 760 mmHg; T_0 = 273.15 K and ρ_0 = 1.293 kg.m^{-3}.

The density ρ may also be expressed as a function of T and x by replacing p_v by $\dfrac{x\,p}{\delta + x}$ in relation (2.12):

$$\rho = \rho_0\,\frac{T_0}{T}\,\frac{p}{p_0}\,\frac{\delta\,(1+x)}{\delta + x} \qquad (2.13)$$

2.3.4 Independent parameters

We have defined 8 parameters characterizing the humid air condition: T, T_h, T_r, HR, x, p_v, i and ρ. The problem is to know how many parameters are independent since it will be the number of parameters to be measured to characterize the humid air condition.

These 8 parameters are related to each other by 6 independent relations (2.2), (2.3), (2.5), (2.6), (2.10) and (2.13) so the variance of the system is equal to 2. Finally, knowing 2 parameters among T, T_h, T_r, HR, x, p_v, i and ρ is enough to deduce the values of the remaining 6 parameters.

3 Humid air diagram

3.1 Aim

The aim is to build a diagram enabling, by a simple reading, the determination of all the characteristic parameters of humid air knowing two of them.

3.2 Diagram plotting

As an example, we are going to plot a diagram in an orthogonal axis system (p_v, T) graduated in mmHg and °C (cf. Appendix 2). The chart will be plot for a total pressure of humid air equal to 760 mmHg.

3.2.1 Saturation curve

We begin to plot on the diagram the saturation curve that is the curve HR = 100% since $p_v = \frac{HR}{100} p_s(T)$ so that $p_v = p_s$ (Th) $\rightarrow$ HR = 100%, by use of tables or of the Dupré formula.

3.2.2 Iso-absolute humidity curves

From relation (2.6): $x = \delta \frac{p_v}{p - p_v}$ we deduce that these curves are vertical straight lines, the diagram being plot for a constant total pressure equal to 760 mmHg. It is thus equivalent to making a double graduation of the abscissa axis: one in mmHg for p_v and the other in $g_w.kg_{da}^{-1}$ for x, the correspondence between them being given by relation (2.6).

<u>Exercise</u>: Graduate the absolute humidity axis between 0 and 16 $g_{water}.kg_{da}^{-1}$ with a step of 2 $g_{water}.kg_{da}^{-1}$on the diagram of Appendix 2.

3.2.3 Iso-relative humidity curve

From relation (2.2): $p_v = \frac{HR}{100} p_s(T)$

For drawing, for a given temperature T, the points corresponding to the relative humidity values 0, 10, 20, …, 90 et 100%, one has just to divide the segment [AB] in 10 equal parts, the point A being the point having the coordinates (T,0) and the point B being the intersection between the isothermal curve (vertical straight line) T with the saturation curve.

<u>Exercise</u>: Plot the curve HR = 30% on the diagram of Appendix 2.

3.2.4 Iso-wet bulb temperature

From relation (2.11): $p_v = p_s(T_h) - \frac{c_{pa}(T - T_h)[p - p_s(T_h)]}{\delta L_{Th}}$

The total pressure p being constant, at constant T_h, the relation (2.11) may be written under the form: $p_v = a_{Th} + b_{Th}$ T, the iso-wet bulb temperature curves are thus straight lines with a slope equal to $b_{Th} = -\frac{c_{pa}[p - p_s(T_h)]}{\delta L_{Th}}$. To plot them, it is enough to know two points:

- For T = T_h, we have according to (2.11): $p_v = p_s(T_h)$, the point is thus on the saturation curve (HR = 100%).
- One has just to determine a second point for another value of T.

<u>Exercise</u>: Plot the curve T_h = 15°C on the diagram of Appendix 2.

3.2.5 Iso-enthalpy curves

From relation (2.5): $i(T,x) = C_{pa}\ T + x\left(L_0 + c_{pv}\ T\right)$

Replacing x by $x = \delta \dfrac{p_v}{p - p_v}$ one obtains: $i(T,x) = C_{pa}\ T + \delta \dfrac{p_v}{p - p_v}\left(L_0 + c_{pv}\ T\right)$

So: $\left(i - c_{pa}\ T\right)\left(p - p_v\right) = \delta\, p_v\left(L_0 + c_{pv}\ T\right)$

Or: $p_v = \dfrac{p\left(i - c_{pa}\ T\right)}{\delta\, L_0 + i + \left(\delta\, c_{pv} - c_{pa}\right)T}$

But: $\left(\delta\, c_{pv} - c_{pa}\right)T = 0.138\ T$ and $\delta\, L_0 = 1556\ kJ.kg^{-1}$ so that: $\left(\delta\, c_{pv} - c_{pa}\right)T << \delta\, L_0$

Enabling to write: $p_v = \dfrac{p\ i}{\delta\, L_0 + i} - \dfrac{p\ c_{pa}}{\delta\, L_0 + i}\ T$

The iso-isenthalpy curves are thus straight lines which slope is: $b_i = -\dfrac{p\ c_{pa}}{\delta\, L_0 + i}$

For low values of i and T_h: $b_i \approx b_{Th}$ since $\dfrac{p\ c_{pa}}{\delta\, L_0 + i} \approx \dfrac{c_{pa}\left[p - p_s\left(T_h\right)\right]}{\delta\, L_0}$ and the iso- isenthalpy curves are rather parallel to the iso-wet bulb temperature curves.

To plot an iso-enthalpy curve, it is enough to know two points, for example:

- For T = 0°C: $p_v = \dfrac{p\ i}{\delta\, L_o + i}$
- For p_v = 0 mmHg: $i = c_{pa}\ T$

Exercise: Plot the iso-enthalpy curve $i = 40\ kJ.kg^{-1}$ on the diagram of Appendix 2.

3.2.6 Iso-density curves

From (2.13): $\rho = \rho_0\ \dfrac{T_0}{T}\ \dfrac{p}{p_0}\ \dfrac{\delta\,(1+x)}{\delta + x}$ where T is the temperature in K.

One can deduce: $T = \dfrac{\rho_0\ T_0}{\rho\ p_0}\left[p - (1-\delta)\,p_v\right] - 273.15$ where T is in °C.

The iso-density curves are thus straight lines which slope is $-\dfrac{\rho_0\ T_0}{\rho\ p_0}\,(1-\delta)$ in an axis system (p_v, T).

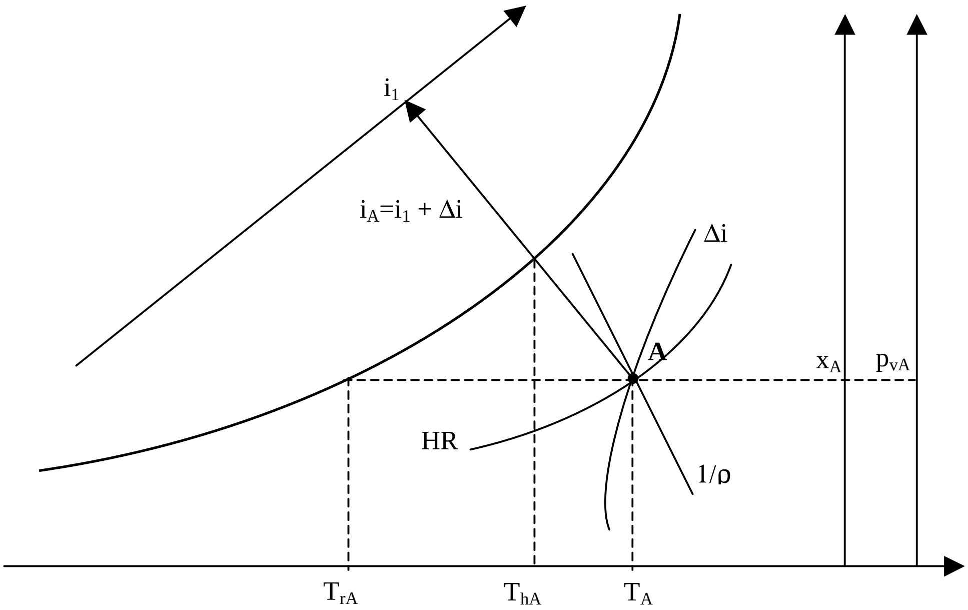
Exercise: Plot the curve $\rho = 1.2\ kg.m^{-3}$ on the diagram of Appendix 2.

3.3 Humid air diagram use

For convenience reason, we plotted the humid air diagram in an orthogonal axis system corresponding to the Carrier diagram. There are several other types of diagram, for example:

- The Mollier diagram: p_v, i
- The Veron diagram: T, x à coordonnées obliques à 92°
- The Missenard diagram: i, x…

A Carrier type diagram is presented in Appendix 3, its only difference compared to the diagram we have previously built is the axis orientation, the principle of the construction of the different curves being the same. The reading of the different humid air parameters on the diagram is done as flows:



Reading characteristics of the air on a humid air diagram

4 « HUMID AIR » PROGRAM

It may also be interesting to write a program (useable on a micro-computer or on a programmable pocket calculator) to calculate the whole air humid parameters knowing two of them. This program can thus replace the humid air diagram.

A Basic written program for a pocket calculator is presented in Appendix 4. It enables the resolution of the more commonly faced problems:

- p, T et HR are known → Thermohygrometer
- p, T et Th are known → Dry and wet bulb thermometer
- p, T et p_v are known → Meteorological data, constant pressure heating.

The presented « Humid Air » program calculates in each case all the air humid parameters that are: T, T_h, T_r, HR, x, p_v, i et ρ.

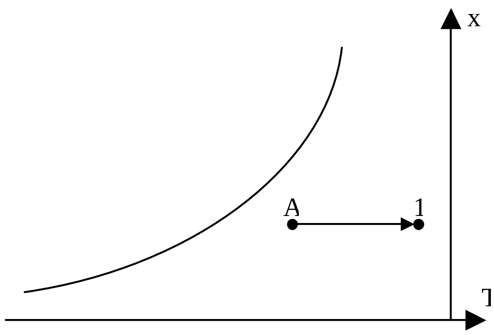
The advantages of the use of this program are:

- Its simple use
- It enables to take into account the true atmospheric pressure value that may be different from 760 mmHg.

The humid air diagram is therefore very useful to visualize the different air humid transformations.

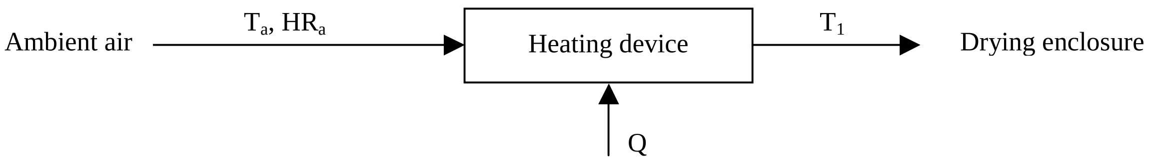
5 EXAMPLES OF HUMID AIR TRANSFORMATION

5.1 Constant pressure heating



Representation of a constant pressure heating in a humid air diagram

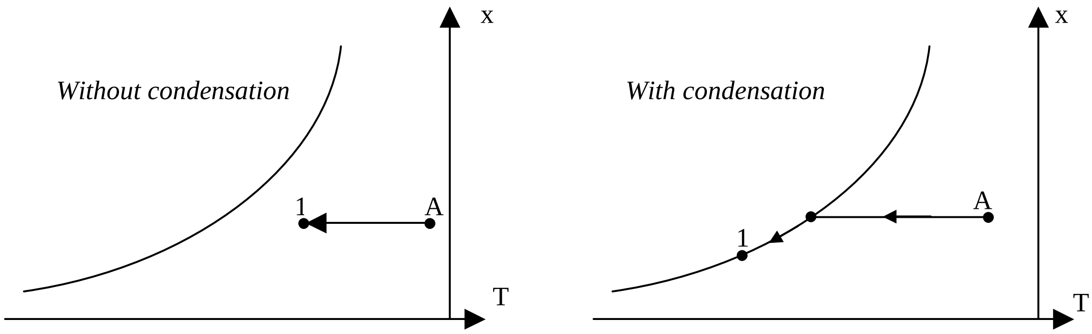
It is the typical transformation applied to the air when it is heated in an heat exchanger, with electric resistances or a in a solar heater:



<u>Exercise</u>:

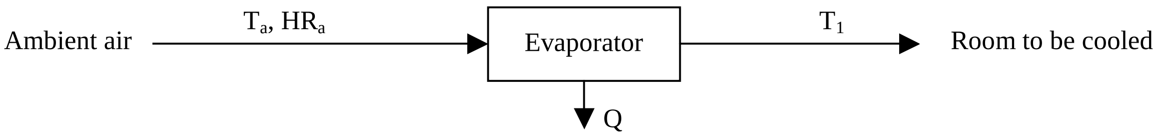
Data: T_a = 25°C, HR_a = 65% and T_1 = 50°C. Calculate all the humid air parameters at the input and at the output of the heating device.

5.2 Constant pressure cooling



Representation of a constant pressure cooling in a humid air diagram

It is the typical transformation applied to the air cooled by the evaporator of a frigorific system, a condensation with a decreasing of the absolute air humidity may occur if the final temperature is lower than the dew point temperature:



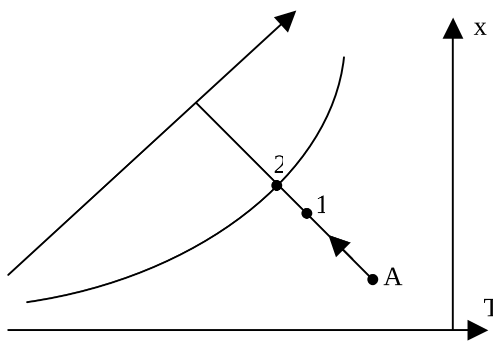
<u>Exercise</u>:

Data: T_a = 30°C, HR_a = 30% and T_1 = 20°C. Calculate all the humid air parameters at the input and at the output of the evaporator.

Calculate the mass of condensed water (for 1 kg of dry air) if T_1 = 5°C.

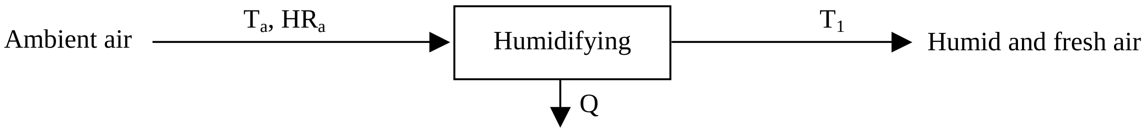
5.3 Adiabatic humidifying

It is the typical transformation applied to the air cooled by flowing through a drier or through a cooling tower:



Representation of an adiabatic humidifying on the humid air diagram

This transformation A → 1 is also called “direct evaporative cooling”. One define a humidifying efficiency of the air as the ratio $\frac{T_A - T_1}{T_A - T_2}$, it is the ration of the effective cooling by the maximal cooling that may be obtained if the air was saturated (HR = 100%) at the end of the transformation.



Exercise:

Data: T_a = 37.5°C et HR_a = 15%. Calculate the minimal temperature that could be reached by adiabatic air humidifying. Calculate the corresponding enthalpy and humidity variations of the air.

In fact, to get a thermal comfort sensation, the air relative humidity must remain below 70%. Calculate the minimal temperature that could be reached if we want to stay in the thermal comfort zone. What is then the humidifying efficiency?

6 AIR HUMIDITY MEASUREMENT

6.1 Hair hygrometer

Measurement principle:

This measurement apparatus enables the air relative humidity HR measurement. Its principle is to amplify mechanically the length variation of a hair that depends on the relative humidity of the surrounding air.

An example of such a hygrometer is presented below. The precision of the measurement is typically ± 3%. A calibration must be done regularly.

A hygrograph uses a length of hair to record changes in humidity. Operating range 0 to 100% RH at an accuracy of +/- 3% between 20 and 100% RH. It is fitted with either a clockwork motor, or a quartz clock switchable between one, seven or 31 days drum rotation.

An example of a hair based hygrometer

6.2 Wet bulb thermometer

The wet bulb thermometer which principle has been given at §2.1 enables the measurement of the wet bulb temperature T_h of the air. The simultaneous measurement of the dry bulb temperature T makes possible the determination of all the humid air parameters. Some precautions must be taken for T_h measurement:

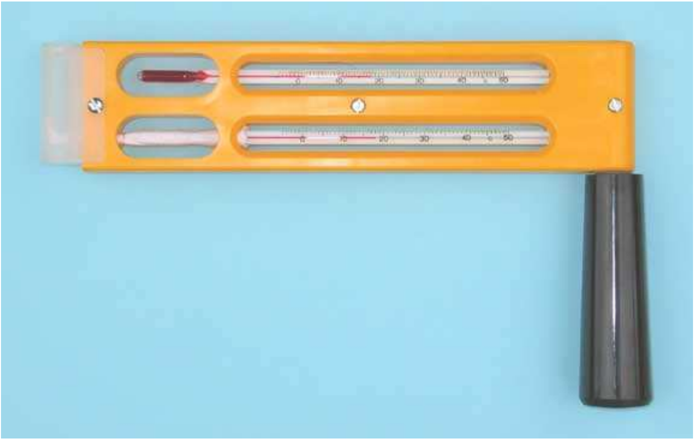
- The wet bulb thermometer must always be recovered by liquid water. If the measurement is too long, the wick dries, its temperature rises and does not correspond any longer to T_h.

- The air speed must be greater than 2 $m.s^{-1}$ so that the radiation heat transfer is negligible compared to the convection heat transfer.
- The dry thermometer must not be disturbed by the wet bulb thermometer that may slightly cool the air.

Mercury or alcohol thermometers may be replaced by thermocouples for an easier data recording.

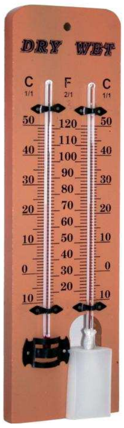
In meteorological shelters naturally ventilated, the value of the psychrometric constant A must be multiplied by a number comprised between 1.13 and 1.20 (1.20 in tropical area). It is better to use a mechanical ventilation to avoid any correction. The minimum relative thermometer/air speed of 2 $m.s^{-1}$ may also be reached by whirling the thermometer as shown below. In these two cases, no calibration is requested.

An example of such a hygrometer is presented below



A whirling hygrometer is a very accurate way of measuring the relative humidity of the air to an accuracy of +/- 2% RH. Folding handle. Supplied with chart and wallet case. An optional slide rule calculator is also available. Mercury or spirit thermometers are available.

An example of a whirling wet bulb thermometer



Comprising two thermometers tubes with double scale graduation, mounted on a weather-proof case. Scales graduated -10 to 50 x 1C and 20 to 120 x 2F. One thermometer kept dry and other has bulb covered with muslin or wick, dipped into a water reservoir, which keeps it wet during long periods of non-use. Comparing the reading of wet and dry thermometer from the humidity and temperature conversion chart included, relative humidity can be worked out.

An example of a static wet bulb thermometer

6.3 Dew point hygrometer

Measurement principle:

A surface is progressively cooled until condensed water apparition on it. The temperature T_{p1} of the surface is noted and the cooling is stopped. The condensed water disappears for a value T_{p2} ($< T_{p1}$) of the surface temperature. One may then consider a value of the dew point temperature given by: $T_r = 0.5 \times (T_{p1} + T_{p2})$.

The detection of the appearance and of the disappearance of the condensed water may be done by an operator or by an optical device. It's the more precise humidity measurement device. No calibration is requested.

An example of such a hygrometer is presented below.

Optidew

High Performance Optical Dew-Point Transmitter

The Optidew high performance optical dew-point transmitter works on the proven, fundamental optical dew point measurement principle, giving unmatched and drift-free long-term performance. It offers a wide measurement range from the equivalent of <0.5 to 100 % rh at ambient temperatures from -40 to +90°C. Optidew provides two linear 4-20 mA outputs in addition to serial communications, allowing configuration and monitoring by a suitable computer or PLC system or via specific Optidew logging software. An adjustable volt-free contact alarm means that Optidew can be used for direct process control. An optional high definition alphanumeric display provides local indication of the measured humidity.

- *Precision process dew point, % rh and temperature measurement*
- *Measurement Range <0.5 to 100 % rh from –40 to +90°C ambient*
- ***0.2°C dew point accuracy (0.15°C optional)***
- *Fundamental drift-free dew point measurement*
- *Rugged, IP66 (NEMA 6) industrial housing*
- *High temperature sensor option to 130°C*
- *Optional local display*

Example of a dew point hygrometer

6.4 Capacitance sensor hygrometer

Measurement principle:

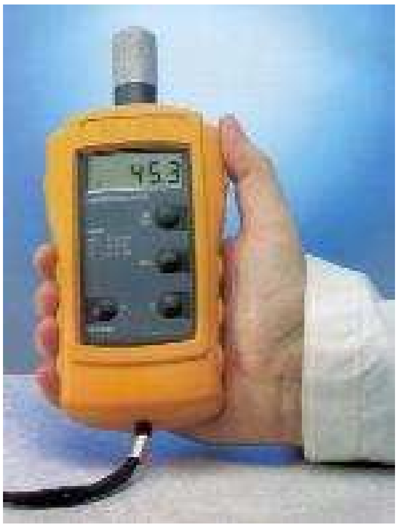
These hygrometers use the capacitance variation of a condenser with the relative humidity of the surrounding air. The value of the air relative humidity is deduced from the capacitance measurement (probe = condenser). An example of this type of hygrometer is presented below. The precision of the measurement is typically ± 3%. A calibration must be done regularly.

Hygrometer Thermo Portable Compact 0.0 - 100.0 % RH.

HI 93640 is a compact portable and versatile hygrometer with a convenient wrist-strap so that you can monitor relative humidity anywhere. The built-in thin-film capacitance sensor assure accurate humidity measurements from 5 to 95%RH with a resolution of 0.1%.

Specifications:

Model	HI 93640
Range	5.0 to 95.0% RH 0.0 to 60.0 ^{0}C 32 tp 140 ^{0}F
Resolution	0.1% RH 0.1 ^{0}C 1 ^{0}F
Accuracy	±2 % RH
Typical EMC	±3% RH
Dimensions	143 x 80 x38 mm
Weight	320 g.



An example of a hygrometer based on a capacitance sensor

Appendix 1: Thermodynamic properties of water

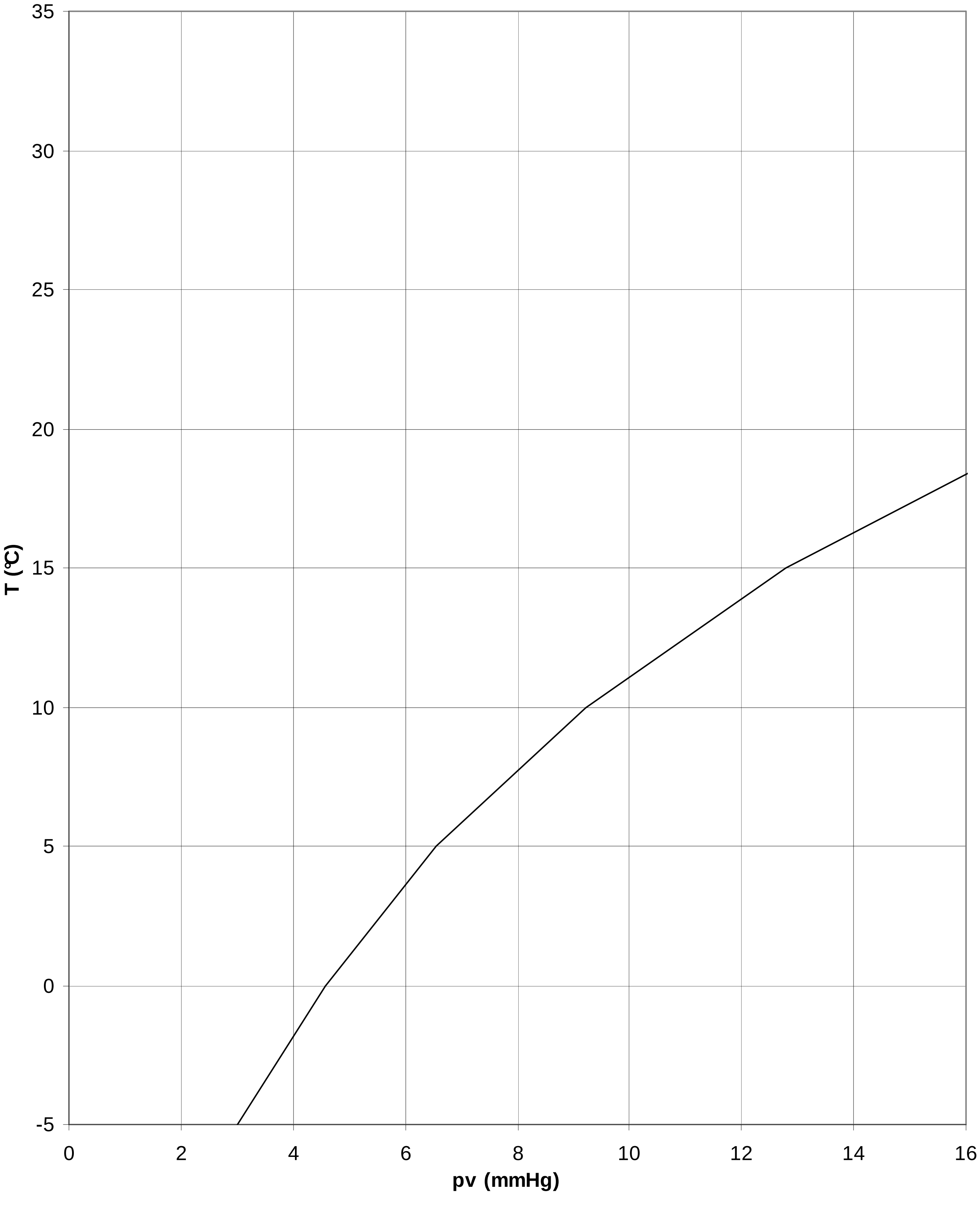
Saturation pressure

T (°C)	Ps (bar)	Ps(mmHg)
0	0.006106	4.581
5	0.008719	6.541
10	0.012277	9.210
15	0.017041	12.78
20	0.02337	17.53
25	0.03166	23.75
30	0.04241	31.81
35	0.05622	42.17
40	0.07375	55.33
45	0.09584	71.90
50	0.12335	92.53
55	0.1574	118.1
60	0.19917	149.4
65	0.2501	187.6
70	0.3117	233.8
75	0.3855	289.2
80	0.4736	355.3
85	0.5781	433.7
90	0.7011	525.9
95	0.8451	634.0
100	1.0131	760.0
105	1.2079	906.1
110	1.4326	1075
115	1.6905	1268
120	1.9854	1489
125	2.3208	1741
130	2.7011	2026
135	3.13	2348
140	3.614	2711
145	4.155	3117
150	4.76	3571
155	5.433	4076
160	6.18	4636
165	7.008	5257
170	7.92	5941
175	8.925	6695
180	10.087	7567
185	11.234	8427
190	12.553	9417
195	13.989	10494
200	15.551	11666
205	17.245	12937
210	19.08	14313

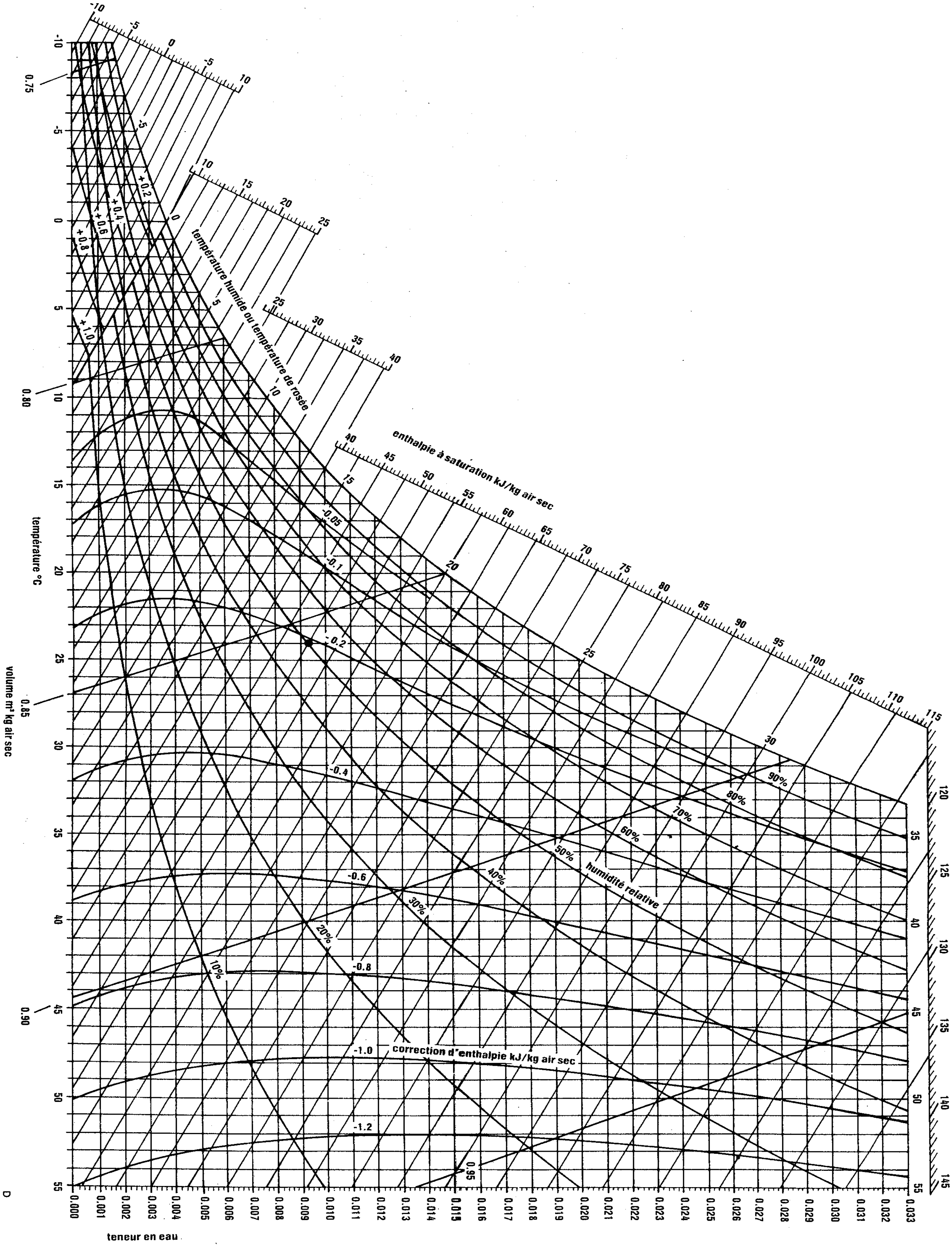
Vaporisation heat

T(°C)	L_T kJ.kg^{-1}
0	2494
20	2448
40	2402
60	2357
80	2309
100	2258
120	2198
140	2143
160	2081
180	2015
200	1942

Appendix 2: Humid air diagram to be completed



Appendix 3: Humid air diagram



Appendix 4: Program « Humid Air »

```
10	"A"
20	INPUT "p(mmHg) = ";P
30	INPUT "T(C) = ";T
40	INPUT "HR(%) = ";HR
50	PS=10^(20.3182-2795/(T+273.15-1.68*LOG(T+273.15))
60	PV=HR*PS/100
70	X=622*PV/(P-PV)
80	GOSOB 440
90	I=1.006*T+X*(2501.6+1.84*T)*.001
100	GOSUB 540
110	RO=.4647*(P-.378*PV)/(T+273.15)
120	GOSUB 660
130	END
140	"B"
150	INPUT "p(mmHg) = ";P
160	INPUT "T(C) = ";T
170	INPUT "Th(C) = ";TH
180	PS=10^(20.3182-2795/(T+273.15)-1.68*LOG(T+273.15))
190	PC=10^(20.3182-2795/(TH+273.15)-1.68*LOG(TH+273.15))
200	XH=.622*PC/(P-PC)
210	LH=2501.8-2.367*TH
220	X=(XH*LH-1.006*(T-TH))/(LH+1.84*(T-TH))
230	PV=X*P/(.622+X)
240	HR=100*PV/PS
250	I=1.006*T+X*(2501.6+1.84*T)*.001
260	X=1000*X
270	RO=.4647*(P-.378*PV)/(T+273.15)
280	GOSUB 440
290	GOSUB 660
300	END
310	"C"
320	INPUT "p(mmHg) = " ;P
330	INPUT "T(C) = " ;T
340	INPUT "pv(mmHg) = " ;PV
350	PS=10^(20.3182-2795/(T+273.15)-1.68*LOG(T+273.15))
360	HR=100*PV/PS
370	GOSUB 440
380	X=622*PV/(P-PV)
390	I=1.006*T+X*(2501.6+1.84*T)
400	GOSUB 540
410	RO=.4647*(P-.378*PV)/(T+273.15)
420	GOSUB 660
430	END
440	T1=-50:T2=200
450	FOR K=1 TO 50
460		TI=(T1+T2)/2
470		PI=10^(20.3182-2795/(TI+273.15)-1.68*LOG(TI+273.15))
480		IF PI>PV THEN LET T2=TI
490		IF PI<=PV THEN LET T1=TI
500		IF (T2-T1)<.05 THEN GOTO 520
510	NEXT K
520	TR=(T1+T2)/2
530	RETURN
540	T1=TR:T2=T
550	FOR K=1 TO 50
560		TH=(T1+T2)/2
570		PC=10^(20.3182-2795/(TH+273.15)-1.68*LOG(TH+273.15))
580		LV=2501.8-2.378*TH
590		PH=PC-1.006*(P-PC)*(T-TH)/(.622*LV)
600		IF PH>PV THEN LET T2=TH
610		IF PH<=PV THEN LET T1=TH
620		IF (T2-T1)< 05 THEN GOTO 640
630	NEXT K
640	TH=(T1+T2)/2
650	RETURN
660	PRINT "T(C) = ";T
670	PRINT "Th(C) = ";TH
680	PRINT "Tr(C) = ";TR
690	PRINT "HR(%) = ";HR
700	PRINT "pv(mmHg) = ";PV
710	PRINT "x(g/kg) = ";X
720	PRINT "i(kJ/kg as) = ";I
730	PRINT "ro(kg/m3) = ";RO
740	RETURN
```