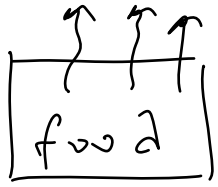
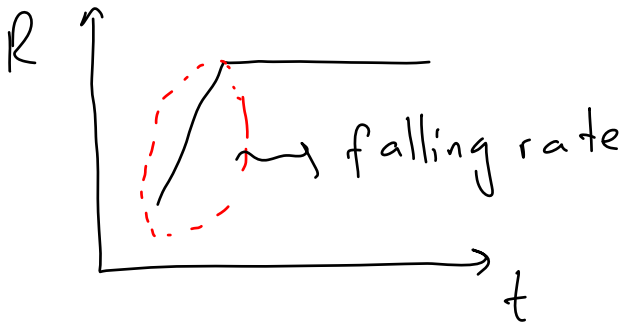
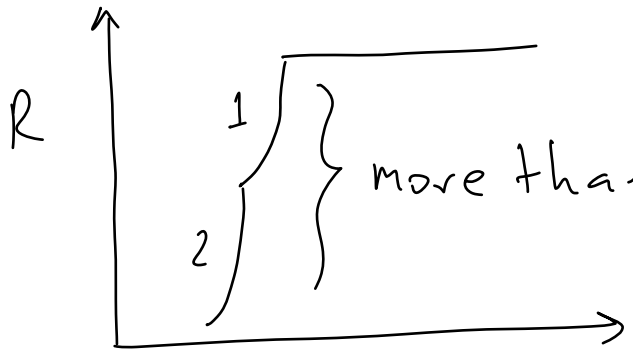
Falling-Rate Period: Drying period during which the rate falls continuously.

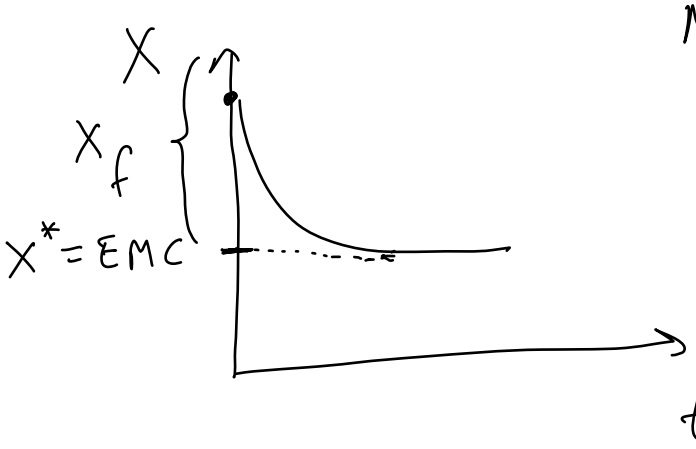


$$R = \frac{X}{\text{Area} \cdot \text{time}}$$



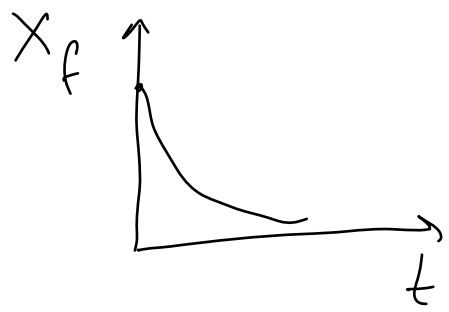


Free Moisture (X_f):



Moisture content in excess of the equil. moisture content (hence free to be removed) at a given air humidity and Temp.

$$X_f = X - X^*$$



Humid Heat (C_s): Heat required to raise the T of unit mass of dry air and its associated vapor through 1°.

Absolute Humidity (H):

$$H = \frac{\text{mass of } H_2O \text{ vapor}}{\text{mass of dry air}} \Rightarrow H = \frac{\text{kg } H_2O}{\text{kg DA}}$$

Relative Humidity (%RH): Ratio of partial pressure of water vapor in gas-vapor mixture to equilibrium vapor pressure at the same T.

Moisture Content (X): Mass of water per mass of solid (dry or wet solid).

$$X_{\text{wet basis}}(\%) = X_{wb}\% = \frac{\text{mass of } H_2O}{\text{mass of wet material}} \times 100$$

$$X_{wb}(\%) = \frac{kg\ H_2O}{kg\ wet\ solid} \times 100$$

$$X_{dry\ basis}(\%) = X_{db}(\%) = \frac{mass\ of\ H_2O}{mass\ of\ dry\ solids} \times 100$$

$$\%\ X_{db} = \frac{kg\ H_2O}{kg\ DS} = \frac{kg\ H_2O}{kg\ wet\ solid - kg\ H_2O} \times 100$$

Unbound Moisture: Moisture in solid which exerts vapor pressure equal to that of pure liquid at the same T.

All the moisture content of a non-hygroscopic material is unbound moisture (cannot hold water).

Water Activity (a_w): Ratio of vapor pressure exerted by water in solid to that of pure water at the same T.

* It is a measure of characteristics of absorbed water by foods.

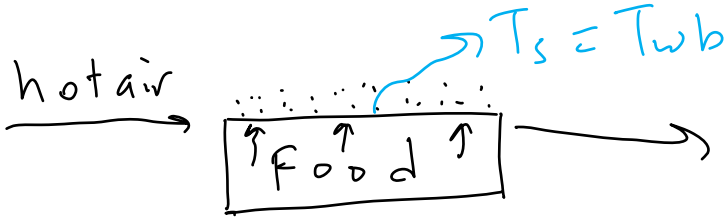
$$a_w = \frac{\%\ RH}{100} \quad \text{or} \quad a_w = \frac{p}{p_w}$$

P: vapor pressure of water inside food.

P_w: pure water vapor pressure exerted at the same T.

Wet-Bulb Temperature (T_{wb}): It is the saturation T of an air-vapor mixture.

At constant drying rate period ⇒



$T_{wb} < T_{db}$

Psychrometric Equations for An Air Water Vapor System:

$$\text{Absolute Humidity (H)} = \frac{18.02}{28.97} \times \frac{P}{P_a - P}$$

$$= \text{kg } H_2O / \text{kg DA}$$

P_a: the total P of air-water vapor mixture

P: partial P of water vapor in air.

Saturation Humidity (H_s): $\frac{kg\ H_2O}{kg\ DA}$

$$H_s = \frac{18.02}{28.97} \times \frac{P_w}{P_a - P_w}$$

P_w: vapor P of pure water at the given T.

Percent Humidity (H_p): $H_p = \frac{H}{H_s} \times 100$

Relative Humidity (%RH): $\%RH = \frac{P}{P_w} \times 100$

Humid Heat (C_s): $kJ/kg\ DA.K$

$C_s = 1.005 + 1.88 \times H \rightsquigarrow SI$

Humid Volume (V_H): m^3 of mixture $/kg\ DA$

$V_H = (2.83 \times 10^{-3} + 4.56 \times 10^{-3} \times H) \cdot T \rightsquigarrow SI$

T in K

Total Enthalpy of An Air-Water Vapor Mixture:

$$H_T = (1.005 + 1.88 \times H)(T - T_r) + H \times \lambda_r \rightsquigarrow \frac{kJ}{kg\ DA} \rightsquigarrow SI$$

T_r : reference T.

λ_r : latent heat of water vapor at T_r.

(*) Latent heat of vaporization :

$$\lambda = a_1 \times (a_2 \times T)^{a_3} \rightsquigarrow kJ/kgDA$$

$a_1 = 267.155$, $a_2 = 374.2$, $a_3 = 0.38$, T in °C.

$$\frac{H - H_{as}}{T - T_{as}} = -\frac{C_s}{\lambda_{as}} = -\frac{1.005 + 1.88 \times H}{\lambda_{as}}$$ and

$$\frac{H - H_{wb}}{T - T_{wb}} = \frac{h/(M_{air} \times k_y)}{\lambda_{wb}} \cong \frac{C_s}{\lambda_{wb}}$$

h: heat transfer coefficient, $kW/m^2.K$

M_{air} : M.wt of air

k_y: mass transfer coefficient: $\frac{kg\ mol}{s.\ mol\ fraction}$

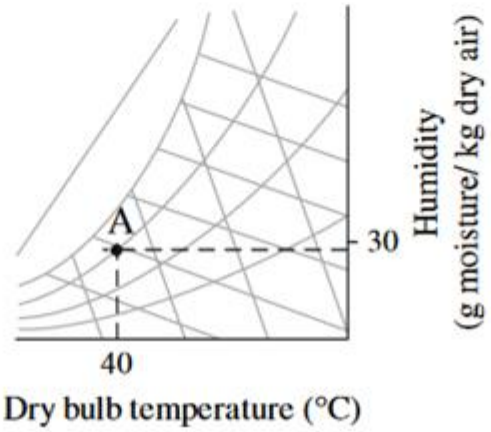
Example 1 :

Find the properties of air with 40 °C dry bulb temperature and 28.5 g water/kg dry air moisture content at 1 atm.

Solution

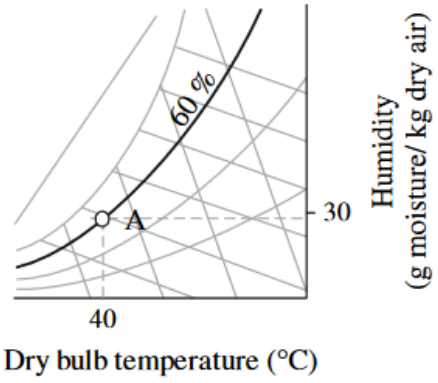
Step 1

i) Locate the point on the psychrometric chart with 40 °C dry bulb temperature and 28.5 g moisture/kg dry air moisture content.
ii) Draw a horizontal line that passes from the point with 28.5 g water/kg dry air moisture content on the y-axis.
iii) Draw a vertical line on the x-axis at the point of 40 °C dry bulb temperature.The point the two lines intersect (point A) represents the point on the psychrometric chart with 40 °C dry bulb temperature and 28.5 g water/kg dry air moisture content.



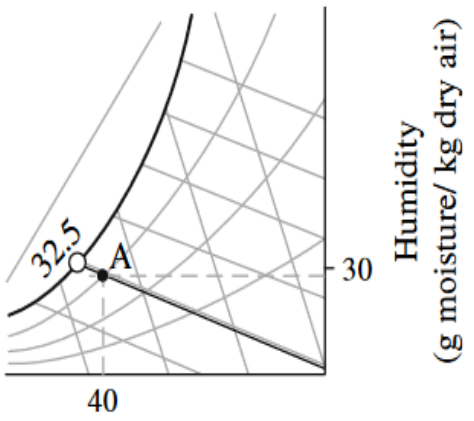
Step 2

i) Find the relative humidity curve that passes through point A.
ii) Read the relative humidity on the relative humidity curve: Read RH = 60%.



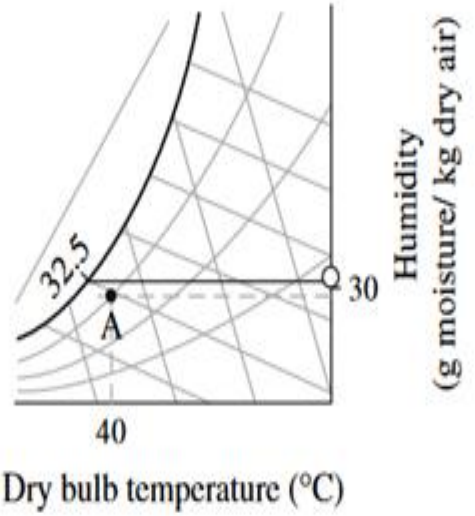
Step 3

i) Draw a line parallel to the wet bulb line that passes through point A.
ii) Read the wet bulb temperature at the point where this line crosses the saturation curve (100% relative humidity curve): Read T_w = 32.5 °C. Alternatively, draw a vertical line down from that point to the dry bulb temperature axis and also read 32.5 °C on the x-axis.



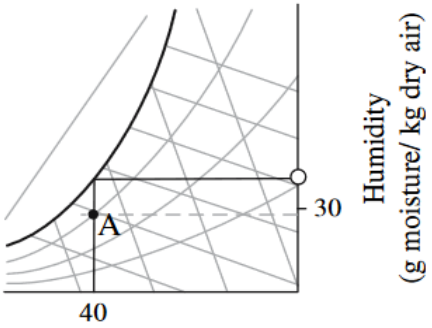
Step 4

i) Draw a line parallel to the x-axis that passes through the wet bulb temperature of 32.5 °C found above.
ii) Read the saturation humidity at the wet bulb temperature on the y-axis: Read $\mathbf{H}_w$ = 0.032 kg water/kg dry air.



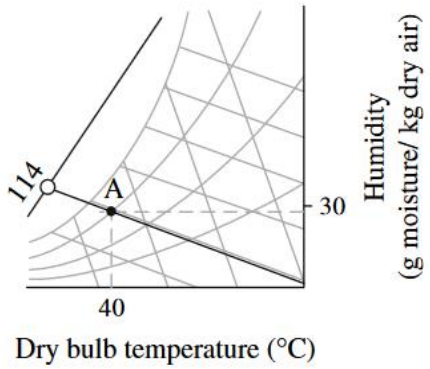
Step 5

i) Draw a vertical line from the x-axis that passes through point A to cross the 100% relative humidity curve.
ii) From the point of intersection, draw a horizontal line to cross the y-axis.
iii) Read the saturation humidity at 40 °C on the y-axis. Read: 0.049 kg water/kg dry air.



Step 6

i) Extend the line parallel to the wet bulb line that passes through point A to cross the enthalpy line.
ii) Read the enthalpy: Read H = 114 kJ/kg dry air.



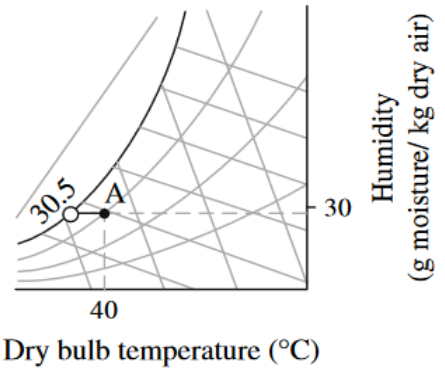
Alternatevely, calculate enthalpy from:

$$H = (1.005 + 1.88\,\mathbf{H})T + \lambda_o \mathbf{H} = (1.005 + 1.88^{*}0.0285)40 + 2501^{*}\mathbf{0.0265 = 113.6\ kJ/kg\ DA}$$

Step 7

i) Extend the constant humidity line (line parallel to the x-axis) that passes through point A to cross the saturation curve (100% relative humidity curve).

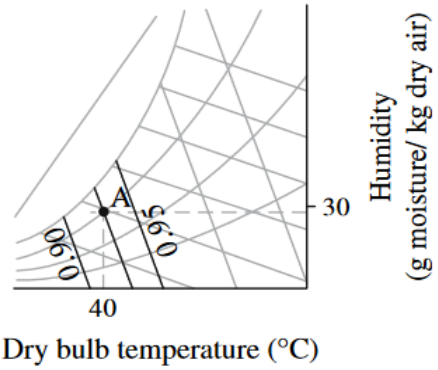
ii) Read the dew-point temperature on the saturation line: Read T_{dp}= 30.5°C.



Step 8

i) Draw a line parallel to the humid volume line that passes through point A.

ii) Read the humid volume: read v_H= 0.93m3/kg dry air.



iii) Alternatively, calculate the humid volume from:

$$v_H = (0.00283 + 0.00456\,\mathbf{H})T = (0.00283 + 0.00456 \times 0.0285)(273 + 40) = 0.926\,\text{m}^3/\text{kg dry air}$$

Calculate the humid heat:

$$c_s = c_A + c_V\mathbf{H} = 1.005 + 1.88\mathbf{H} = 1.005 + 1.88 \times 0.0285 = 1.059\,\text{kJ/kg °C}$$

Example 2 :

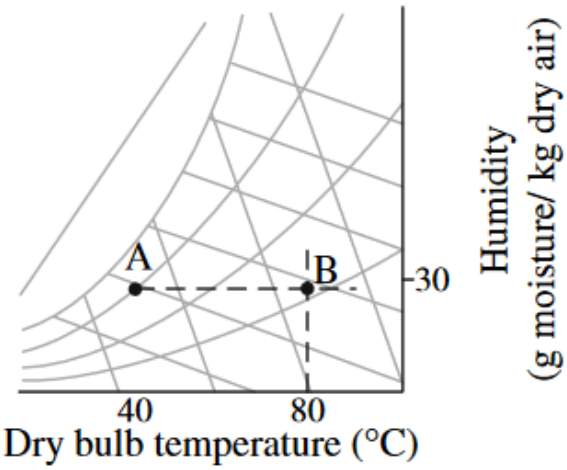
The air of Example 1 is heated to 80 °C. Find the relative humidity, wet bulb temperature, dew-point temperature, humid volume, and enthalpy of the air.

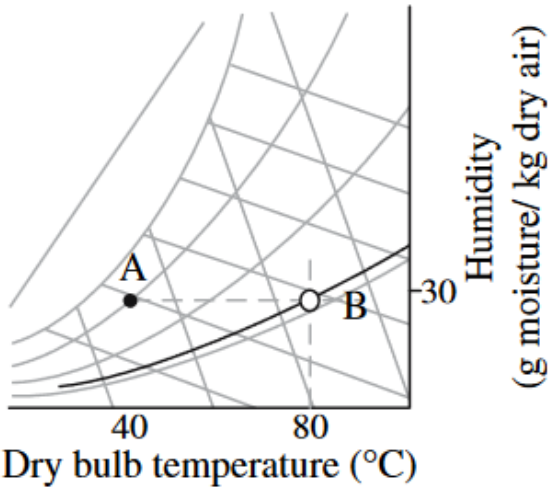
Solution

Step 1
Since only sensible heat is added to the air, its moisture content and dew-point temperature remain constant. Therefore:

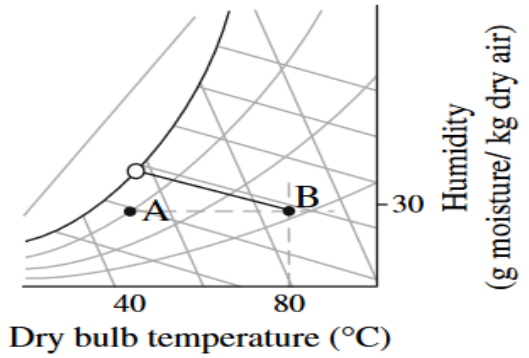
i) Draw a horizontal line from point A of Example 1 .
ii) Draw a vertical line on the x-axis at the point of 80 °C dry bulb temperature. The point at which the two lines intersect (point B) represents the point on the psychrometric chart with 80 °C dry bulb temperature and 28.5 g water/kg dry air moisture content.

Step 2
Find the properties of air at point B following the same procedure as in Example 1 for point A.

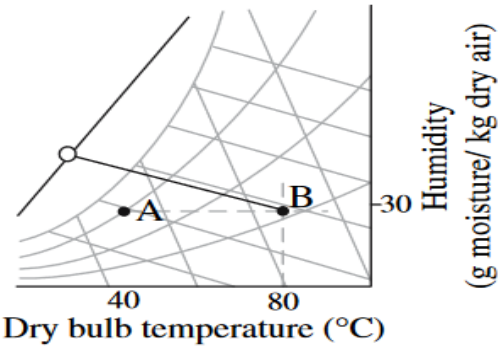




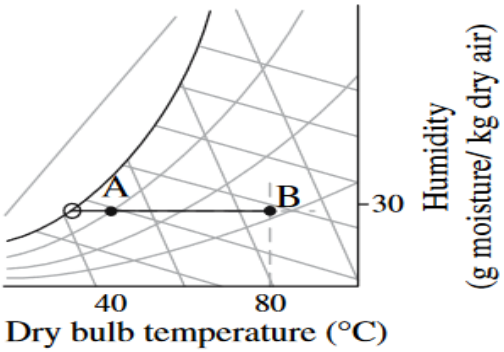
Relative humidity = 9.5%



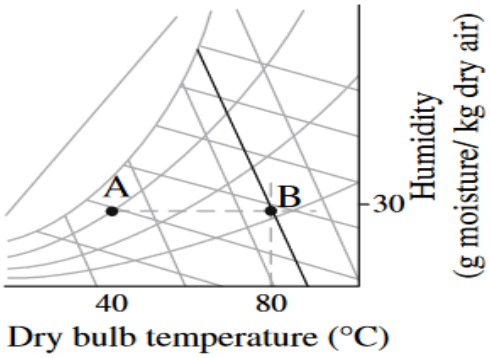
Wet bulb temperature = 39°C



Enthalpy = 158 kJ/kg dry air



Dew-point temperature = 30.5°C



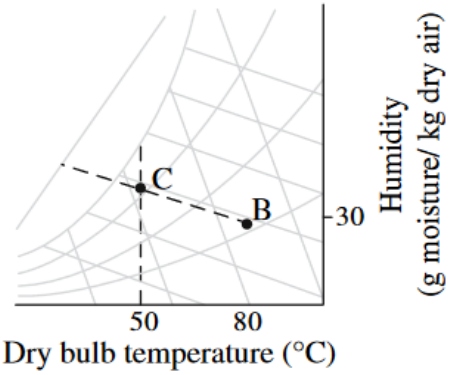
Humid volume = 1.045 m^3/kg dry air

Example 3 :

The heated air of Example **2** passes through a dryer, picking up moisture adiabatically there, and leaves the dryer at 50 °C. Determine the properties of the air at the exit of the dryer.

Solution

Step 1
The air flows through the dryer following an adiabatic saturation line. The point of intersection (point C) of the adiabatic saturation line passing through point B with the vertical line on the x-axis passing through 50 °C dry bulb temperature represents the air at the exit of the dryer.



Step 2

Following the same procedure as in the previous examples, find the properties of air at point C:

Relative humidity = 51%

Wet bulb temperature = 39 °C

Enthalpy = 158 kJ/kg dry air

Dew-point temperature = 37 °C

Humid volume = 0.975 m^3/kg dry air