Topic 3.2. Humidity Psychrometric Chart

Last lecture

- ✓ Basic concepts and terminology related to humidity

This lecture

- ✓ Psychrometric (humidity) terminology
- ✓ Plot processes on a psychrometric chart and analyze processes

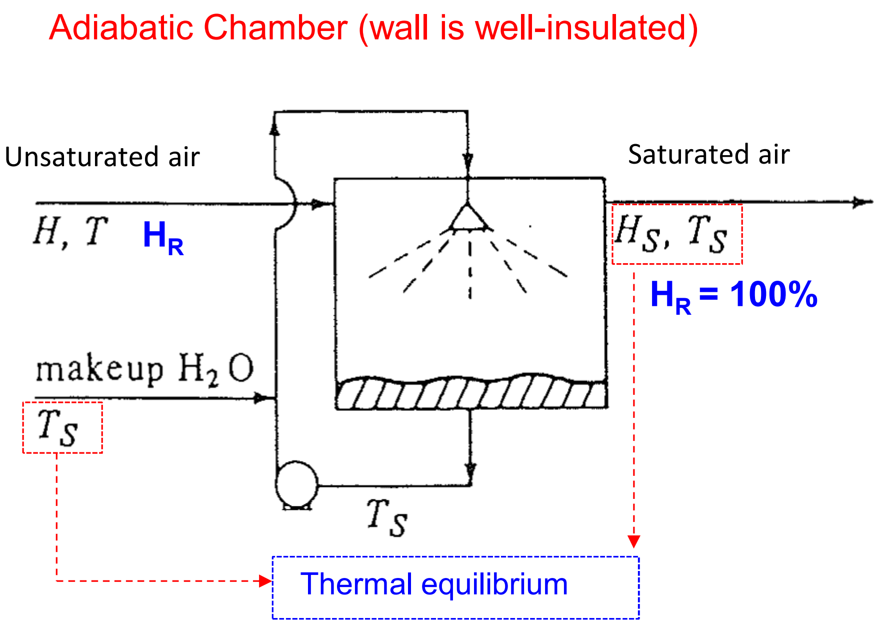
Part of this lecture is obtained from notes of professor Zayed Hamamreh – ChE – University of Jordan

Terminologies

○ Adiabatic saturation temperature Ts

- If a mass of air is brought to contact with water under adiabatic conditions (no heat transfer with the exterior), the humidity of the air increases until saturation is reached (H_R=100%).

- Since there is no external source of heat, water is evaporated using heat from the air itself.
- Consequently, the air is cooled at the same time that it is humidified.
- The process described is called "adiabatic saturation" and the temperature reached at saturation is called the "adiabatic saturation temperature".



An enthalpy balance can be written over this process. The enthalpy balance is based on temperature T_s, as a datum. Then the total enthalpy of the entering gas equals that of the leaving gas.

$$C_{pg}(T - T_s) + H\lambda_s + HC_{pv}\,(T - T_s) = H_s\,\lambda_s$$

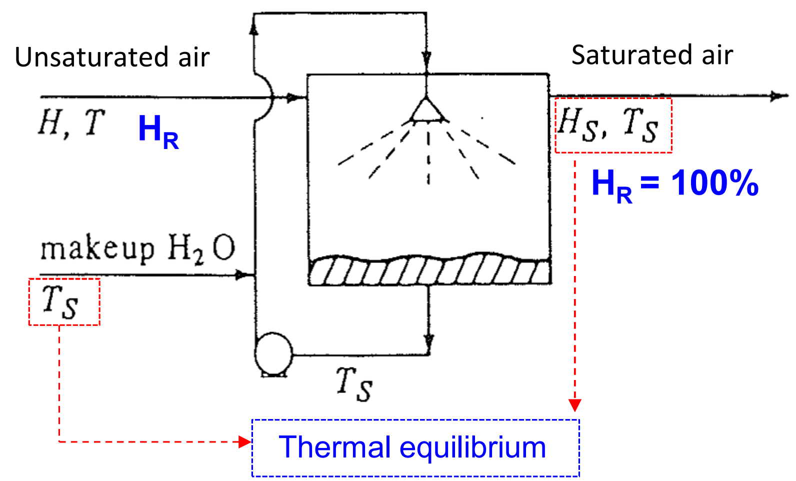
Given the humid heat, $\boldsymbol{C_s = C_{pg} + HC_{pv}}$

$$C_s(T - T_s) + H\lambda_s = H_s\,\lambda_s$$

rearrange

$$\frac{H - H_s}{T - T_s} = -\frac{\boldsymbol{C_s}}{\lambda_s} = -\frac{\boldsymbol{C_{pg} + HC_{pv}}}{\lambda_s}$$

Adiabatic Chamber (wall is well-insulated)



Wet bulb (saturation) temperature T_{wb} or T_w or T_s (for air-water system)

A temperature that is used to study the non-equilibrium systems at adiabatic conditions.

Assumptions

- Gas flow at turbulent condition with no change in its properties
- Gas is not saturated with liquid
- **Bulb** must be completely wet
- Supplied liquid should be at T_{wb}

For water-air system ⇨ $T_w = T_s$

For other systems ⇨ $T_w \neq T_s$

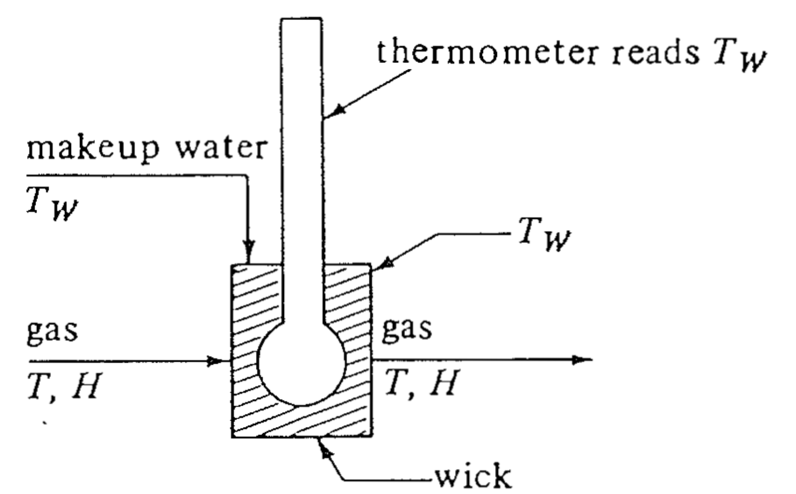
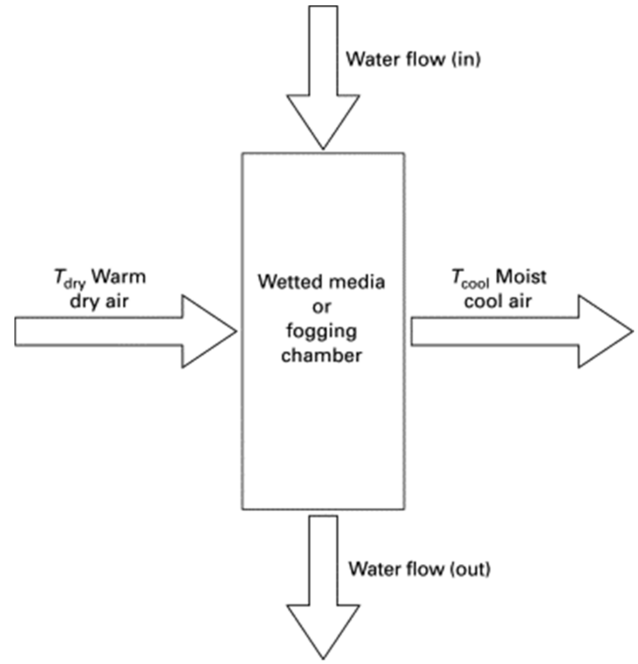


FIGURE 9.3-4. *Measurement of wet bulb temperature.*

The rate of sensible heat transferred between liquid and gas phase

$$q = h_y A (T_g - T_i)$$

$$q = m_v [\lambda_v + C_{pv} (T_g - T_v)]$$



But can be related to molar mass of water and the mass flux per unit area ⇨ $m_v = M_v\, N_v\, A$

$$N_v = k_y \frac{(y_i - y)}{(\mathbf{1} - \boldsymbol{y})_{LM}}$$

k_y is the mass transfer coefficient [mol/area.mol fraction]
y_i is the mole fraction of the vapor in saturated gas at interface at T_w
y is the mole fraction of the vapor in the air stream

$$y_i = \frac{\frac{H_w}{M_v}}{\left(\frac{H_w}{M_v} + \frac{1}{M_g}\right)}$$

Assuming the mole fraction of vapor in gas phase is negligible

$$\Rightarrow \quad \boldsymbol{(1-y)_{LM} \approx 1}$$

$$N_v = k_y A(y_i - y)$$

Substitute in the energy equation

$$q = m_v\left[\lambda_v + C_{pv}\left(T_g - T_v\right)\right]$$

$$m_v = M_v\, N_v\, A$$

$$\Rightarrow \quad q = M_v\, k_y\, A\,(y_i - y)\left[\lambda_v + C_{pv}\left(T_g - T_v\right)\right] = h_y A\left(T_g - T_i\right)$$

$$M_v\, k_y\, A\left(\frac{\frac{H_w}{M_v}}{\left(\frac{H_w}{M_v} + \frac{1}{M_g}\right)} - \frac{\frac{H_g}{M_v}}{\left(\frac{H_g}{M_v} + \frac{1}{M_g}\right)}\right)\left[\lambda_v + C_{pv}\left(T_g - T_v\right)\right] = h_y A\left(T_g - T_w\right)$$

Further Assumptions

- $\lambda_v \gg C_{pv}(T_g - T_v)$
- $\frac{1}{M_g} \gg \frac{H_g}{M_v}$ and $\frac{1}{M_g} \gg \frac{H_w}{M_v}$

$$k_y \left(H_w M_g - H_g M_g\right)[\lambda_v] = h_y A\left(T_g - T_w\right)$$

$$k_y M_g\left(H_w - H_g\right) \lambda_v = h_y A\left(T_g - T_w\right)$$

$$\frac{H_g - H_w}{T_g - T_w} = -\frac{h_y}{k_y\, M_g\, \lambda_v}$$

For turbulent flow of gas heat transfer by conduction and convection between liquid and solid boundary

$$h_y = G\, C_p \propto Re^n\, Pr^{-m}$$

For mass transfer between phases

$$k_y = \frac{G}{M_g} \propto Re^n\, Sc^{-m}$$

$$Re = \frac{\rho\, d\, v}{\mu} \qquad Pr = \frac{\mu C_p}{k} \qquad Sc = \frac{\mu}{\rho\, D_{AB}}$$

Substitute for h_y and k_y

$$\frac{H_g - H_w}{T_g - T_w} = -\frac{h_y}{k_y\, M_g\, \lambda_v} = -\frac{C_p}{\lambda_v}\left(\frac{Sc}{Pr}\right)^m$$

The relation between h_y and k_y ⇨ $$\frac{h_y}{k_y\, M_g} = C_p\left(\frac{Sc}{Pr}\right)^m$$

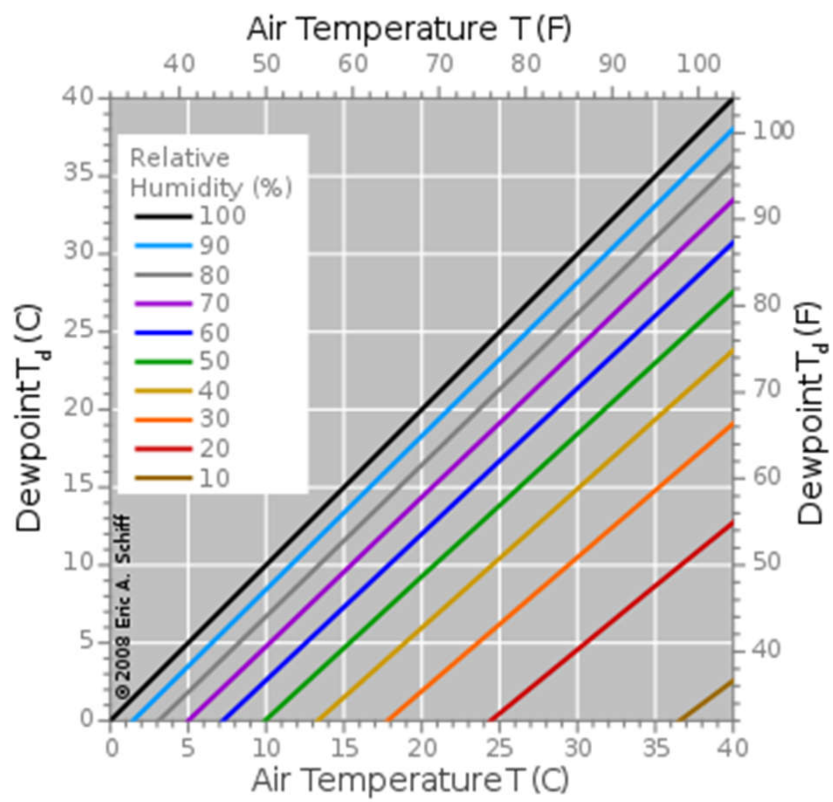
For water-air system $$\frac{h_y}{k_y\, M_g} = 0.24$$ and $$T_w = T_s$$

Dew point temperature T_{dew}

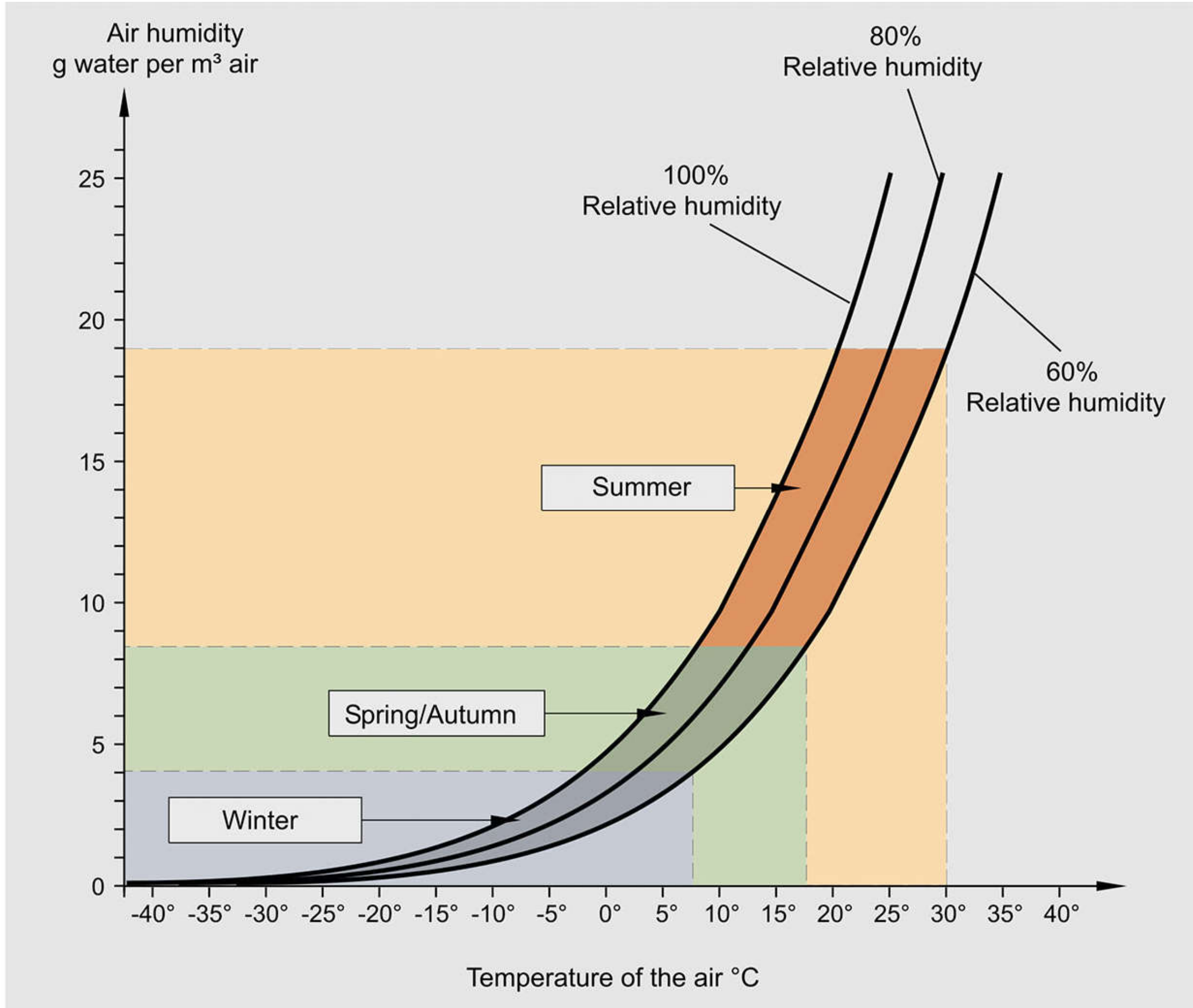
The dew point is the temperature to which air must be cooled to become saturated with water vapor, assuming constant air pressure and water content

- The dew point is affected by humidity. When there is more moisture in the air, the dew point is higher
- When the temperature is below the freezing point of water, the dew point is called the frost point

$$T_{\text{dp}} \approx T - \frac{100 - \text{RH}}{5}$$



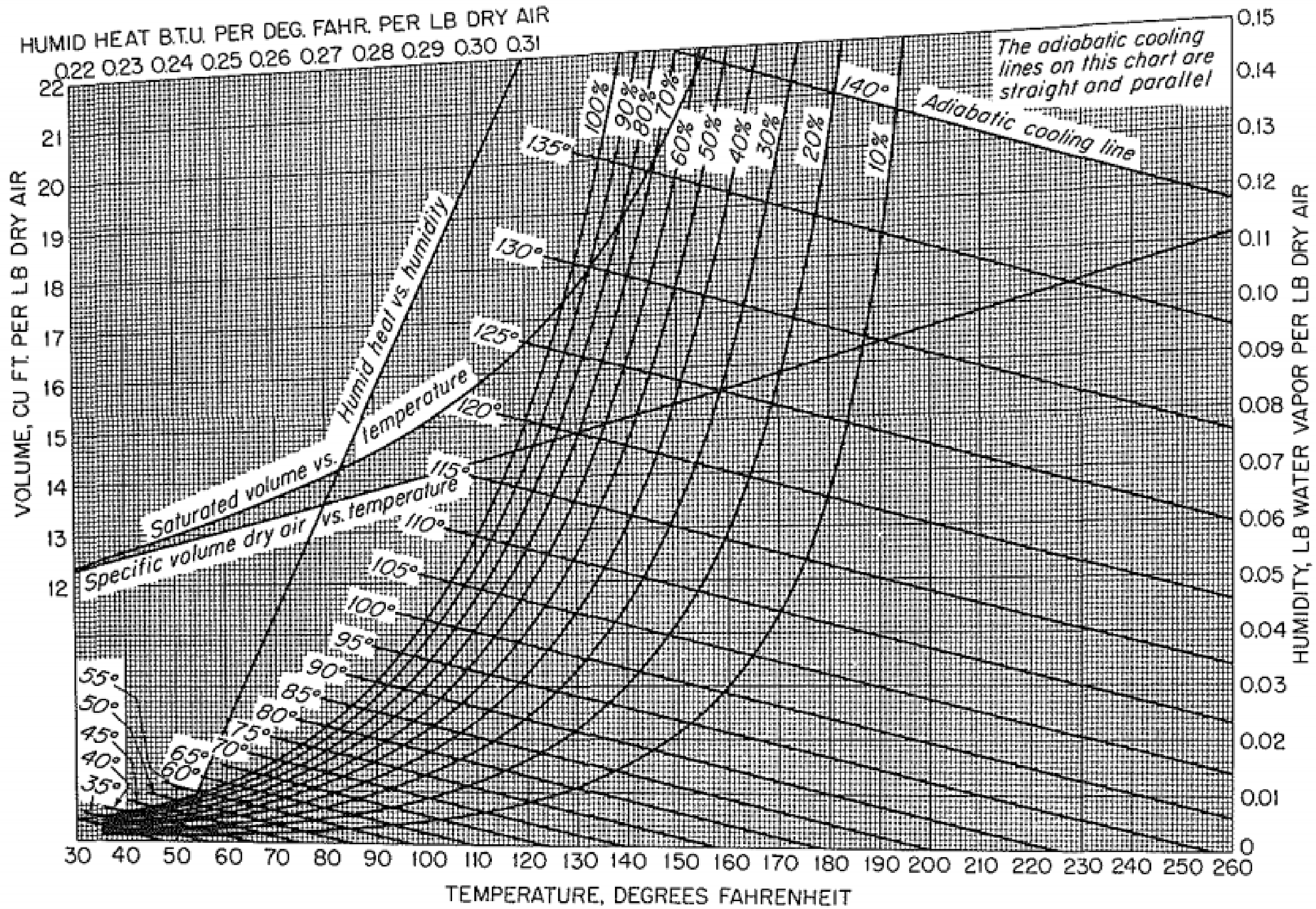
The dew point and the four seasons



Psychrometric Humidity charts (1)

There are five different lines and curves in this graph

1. Percentage humidity
2. Adiabatic cooling lines
3. Specific volume of dry air
4. Volume of saturated air
5. Humid heat



Psychrometric charts (1)

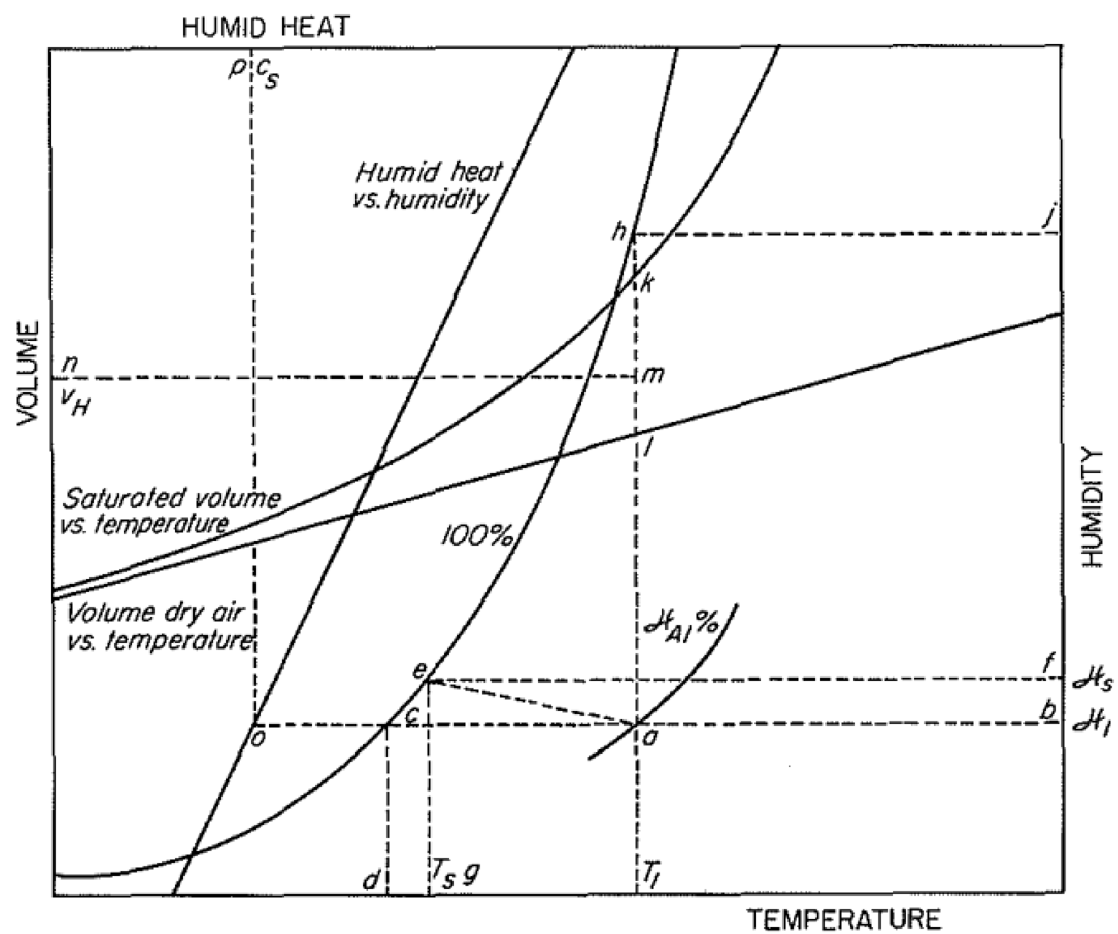
You will be given two values and required to obtain the other parameters

For example: given the temperature of unsaturated air, T_1 and the percentage humidity of air, $H_{A1}\%$.

Humidity of air: Point ***b*** is found by moving along line T_1 to the given percentage humidity of air, $H_{A1}\%$ then a horizonal line to Humidity axis.

$$Humidity = \frac{mass\ of\ vapor}{mass\ of\ dry\ gas}$$

$$\mathscr{H} = \frac{P_w}{P - P_w}\left(\frac{M_w}{M_A}\right)$$

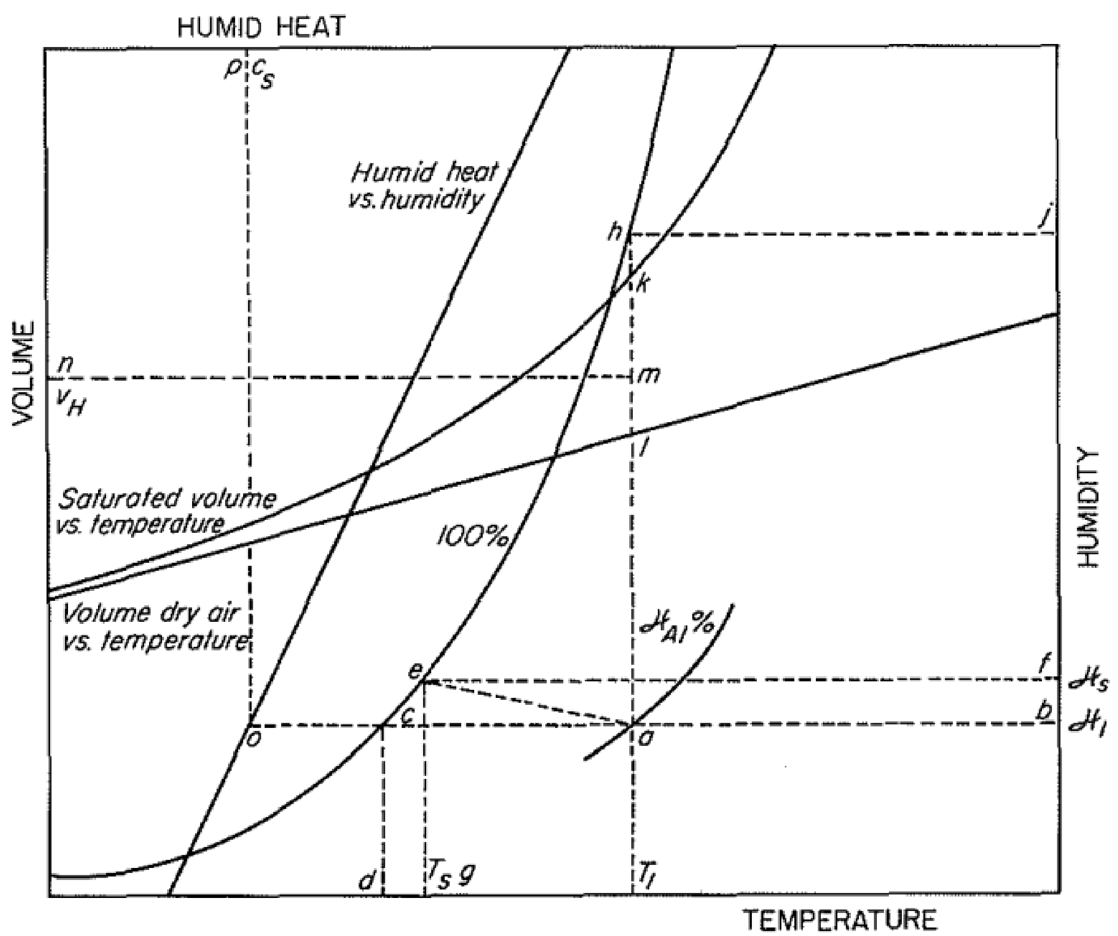


Psychrometric charts (1)

Dew point: Point $\boldsymbol{d}$ is found by moving line T_1 to the given percentage humidity of air, $H_{A1}\%$ then a horizonal line to 100% humidity curve, then down to T-axis.

Dew point can be approximated in SI unit by

$$T_{\mathrm{dp}} \approx T - \frac{100 - \mathrm{RH}}{5}$$



Psychrometric charts (1)

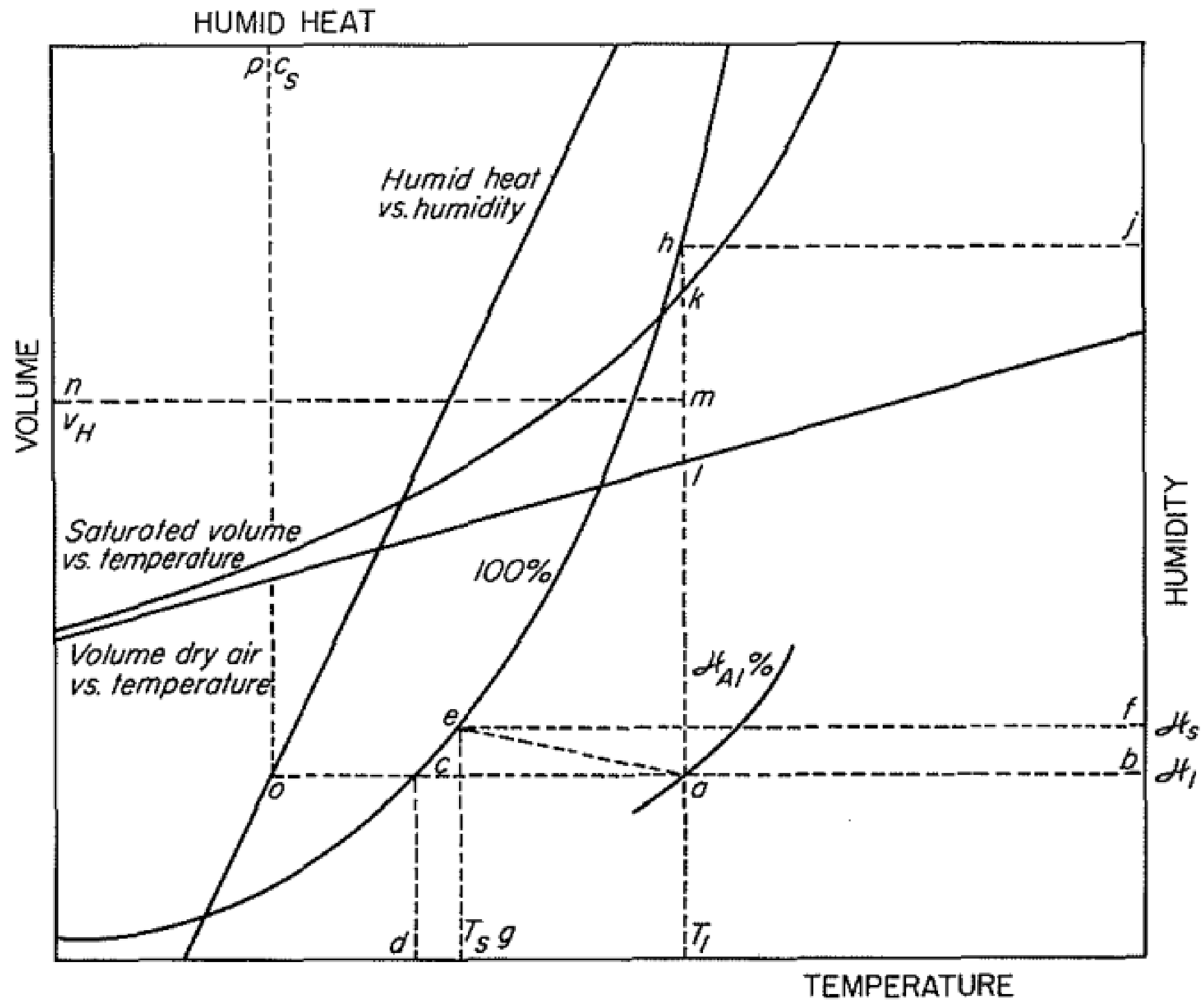
Humid volume: Point $\boldsymbol{m}$ is found by moving along line $\boldsymbol{lk}$ a distance of $\frac{H_A}{100} \times \overline{lk}$ from point $\boldsymbol{l}$.

$$v_H = v_l + \frac{H_A}{100}(v_k - v_l)$$

$$v_H \text{ m}^3/\text{kg dry air} = \frac{22.41}{273}\, T \text{ K} \left(\frac{1}{28.97} + \frac{1}{18.02} H\right)$$

$$= (2.83 \times 10^{-3} + 4.56 \times 10^{-3}\, H) T \text{ K}$$

Saturated Humidity temperature: Point $\boldsymbol{g}$ is found by moving from point $\boldsymbol{a}$ along adiabatic cooling line to the percentage humidity curve, point e, then move down to T-axis to point . $\boldsymbol{g}$

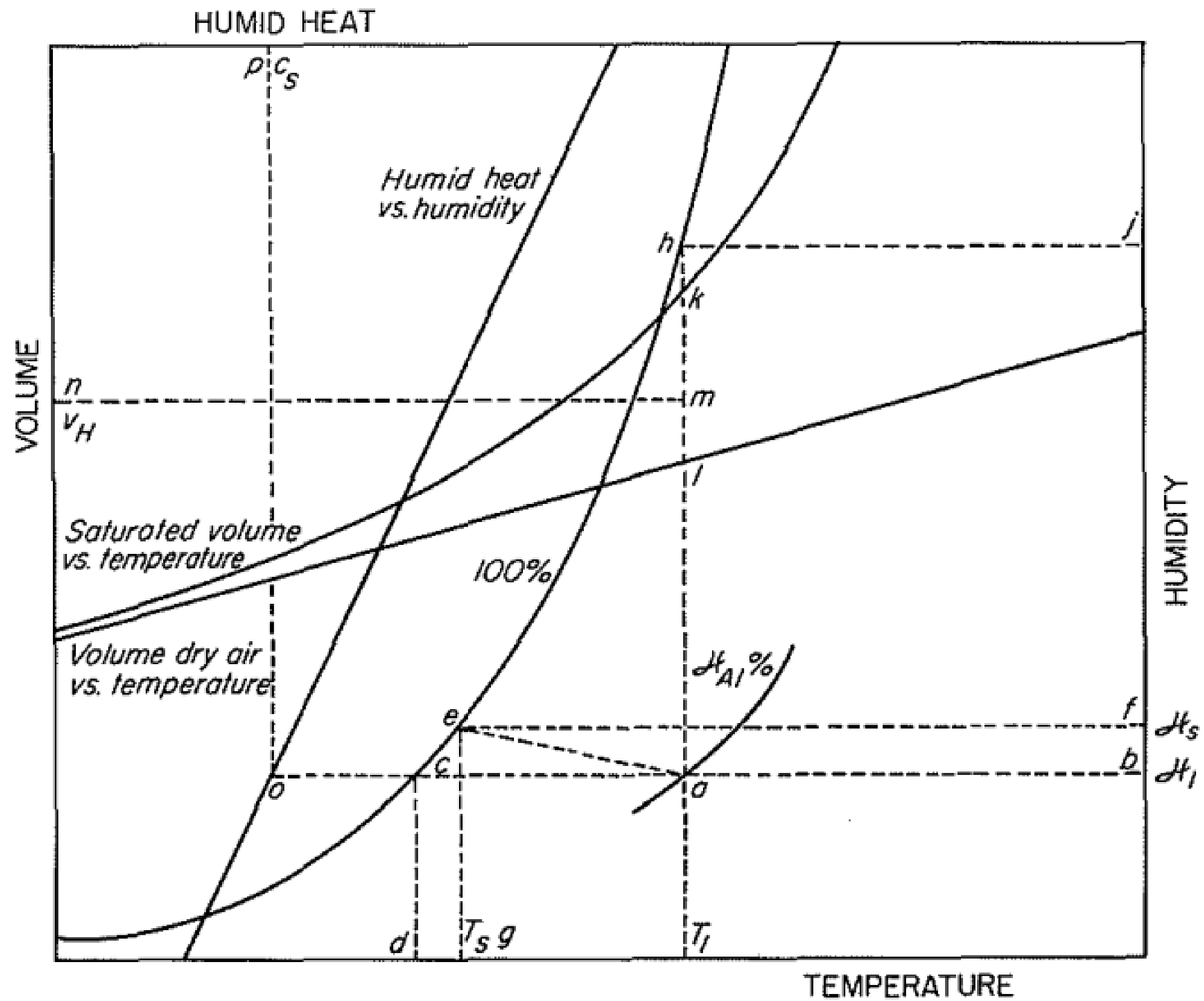


Psychrometric charts (1)

Humid Heat: from point $\boldsymbol{a}$ move horizontal to Humid heat line, point $\boldsymbol{o}$, then move vertically to hit humid heat axis, point $\boldsymbol{p}$

$$\boldsymbol{C_s = C_{pg} + HC_{pv}}$$

where C_{pg}, and C_{pv} are the specific heats of gas and vapor, respectively.



Example 3.4. Humidity of air

The air in a room is at 65.6°C (150°F) and a pressure of 101.325 kPa and contains water vapor with a partial pressure p_v = 3.35 kPa. Calculate the following:

(a) Humidity, H and mole fraction of water in air, y_v
(b) Saturation humidity, HS and mole fraction of saturated water in air, y_v
(c) the percentage relative humidity

Solution **(from steam tables)** Saturation pressure p_{vo} = 25.67 kPa

$$H = \frac{p_v}{p - p_v}\left(\frac{M_v}{M_{air}}\right) = \frac{3.35}{101.325 - 3.35}\left(\frac{18}{29}\right) = 0.021\,\frac{kg H_2O}{kg\ air}$$

$$H_s = \frac{p_{vo}}{p - p_{vo}}\left(\frac{M_v}{M_{air}}\right) = \frac{25.67}{101.325 - 25.67}\left(\frac{18}{29}\right) = 0.2106\,\frac{kg H_2O}{kg\ air}$$

$$y_v = \frac{p_v}{p_T} = \frac{HM_g}{(HM_g + M_v)} = \frac{0.021\,(29)}{0.021\,(29) + 18} = 0.033$$

$$y_{v-sat} = \frac{p_{vs}}{p_T} = \frac{H_s M_g}{(H_s M_g + M_v)} = \frac{0.2106\,(29)}{0.2106\,(29) + 18} = 0.253$$

The percentage humidity, by definition $= 100\mathscr{H}/\mathscr{H}_0$

$$H_p = \frac{H}{H_s} \times 100 = \frac{0.021}{0.2106} \times 100 = 10\,\%$$

$$H_P = \frac{y_v}{y_{v-sat}} \times 100 = \frac{0.033}{0.253} \times 100 = 10\,\%$$

$$\text{Percentage humidity} = \left(\frac{P - P_{w0}}{P - P_w}\right) \cdot \left(\frac{P_w}{P_{w0}}\right) \times 100$$

$$= \frac{(P - P_{w0})}{(P - P_w)} \times (\text{percentage relative humidity})$$

$$H_p = \frac{p - p_{vo}}{p - p_v}\left(\frac{p_v}{p_{vo}}\right) \times 100 = \frac{101.325 - 25.67}{101.325 - 3.35}\left(\frac{3.35}{25.67}\right) \times 100 = 10\ \%$$

The air in a room is at 65.6°C (150°F)
The percentage relative humidity is 10 %

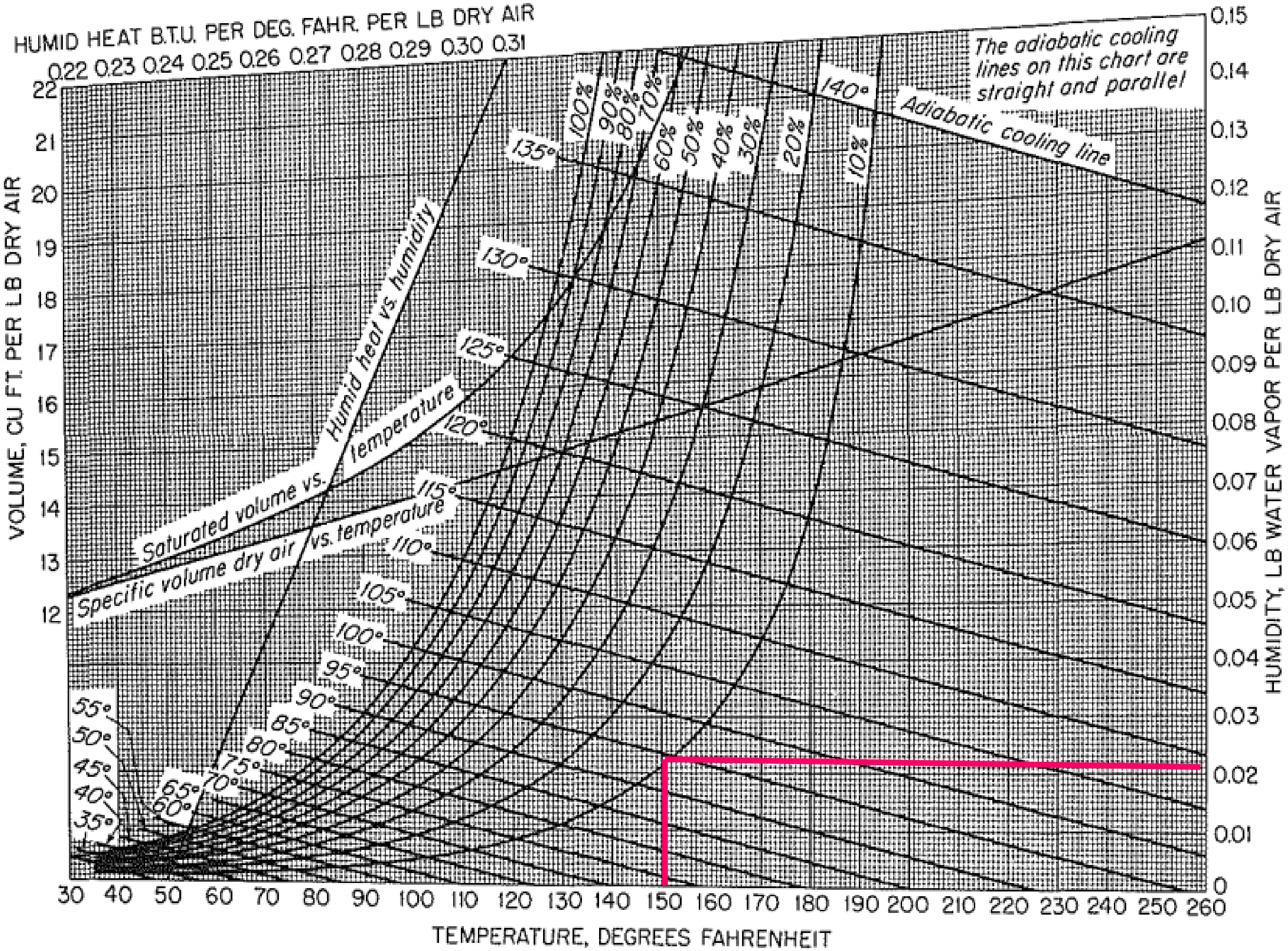
Example 3.5. Use of psychrometric charts

The air in a room is at 65.6°C (150°F) and a percentage humidity of 10%. Use psychrometric chart to obtain:

1. Humidity

Humidity

$$H = 0.021\,\frac{kgH_2O}{kg\;air}$$



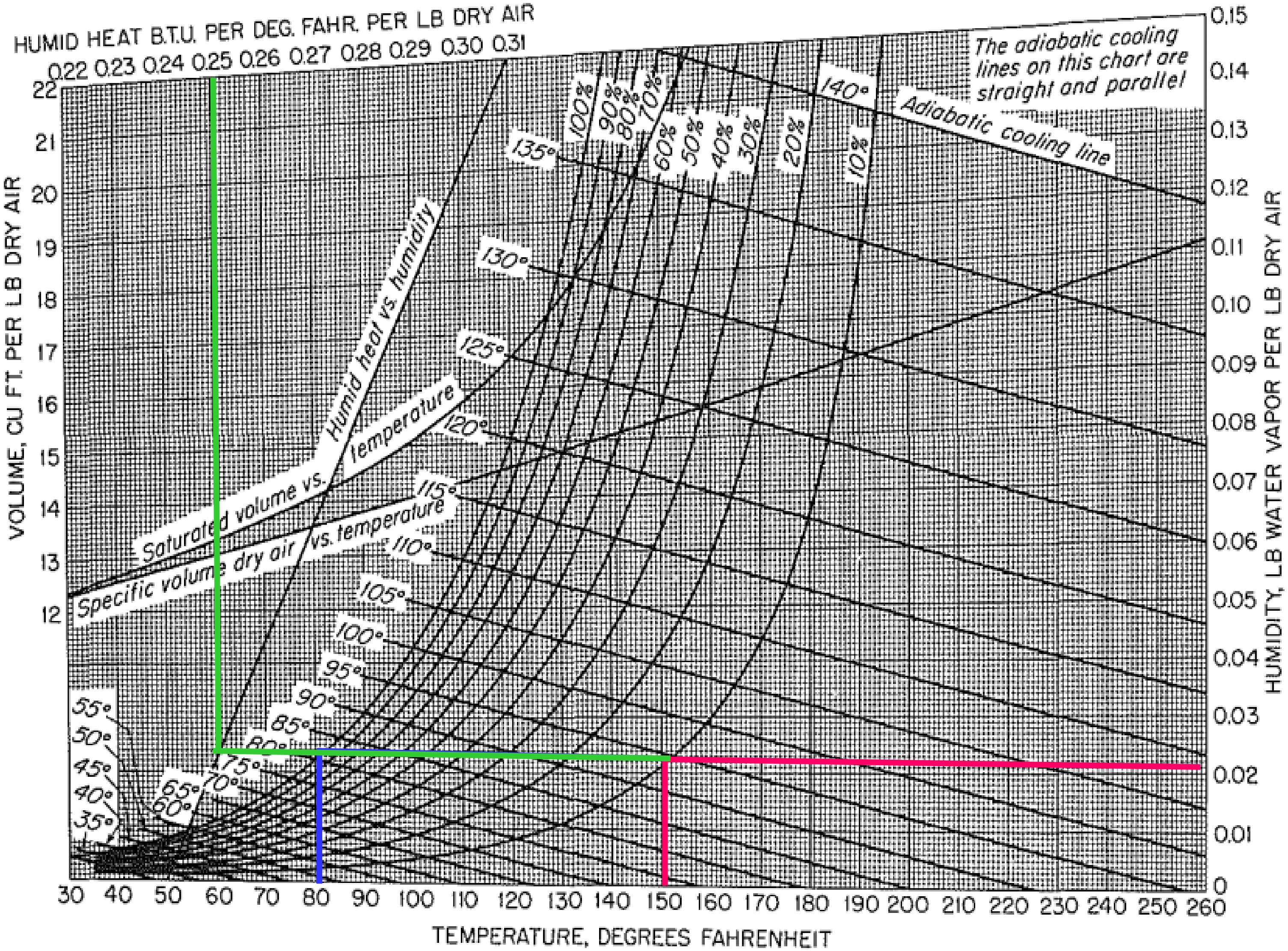
Dew point

T dew $= 80\ F$

Humid Heat

$$C_s = C_{pg} + HC_{pv}$$

= 0.25 Btu/F.lb



Humid volume

$$H = 0.021\,\frac{kgH_2O}{kg\ air}$$

$$v_H = v_l + \frac{H_A}{100}(v_k - v_l)$$

$$v_l = 15.3\ ft^3/lb$$