Aire Húmedo

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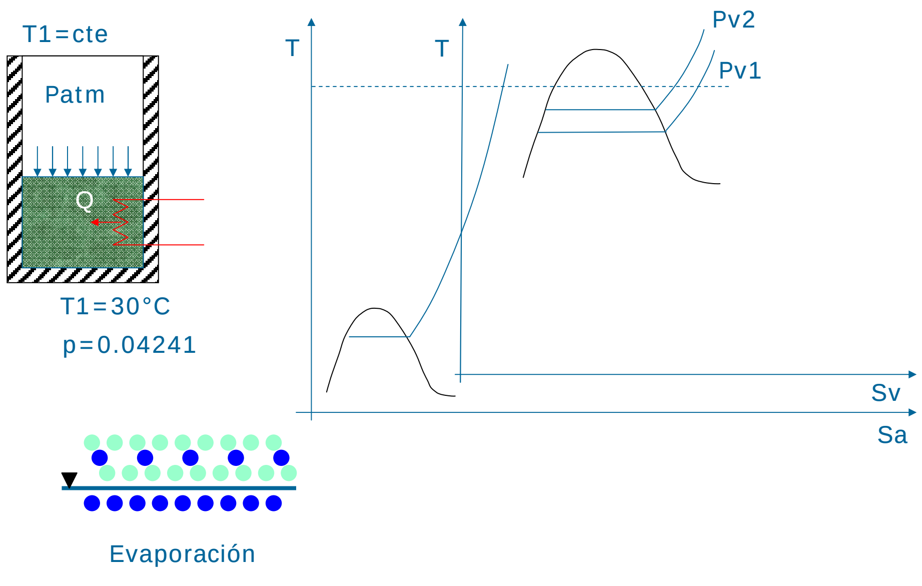
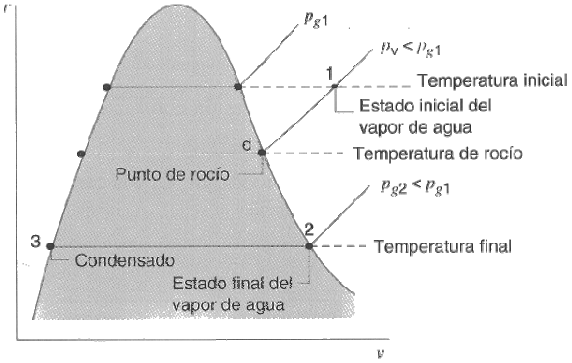
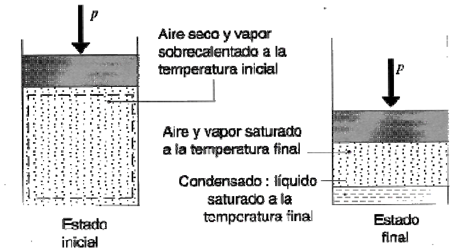


Temperatura de rocío





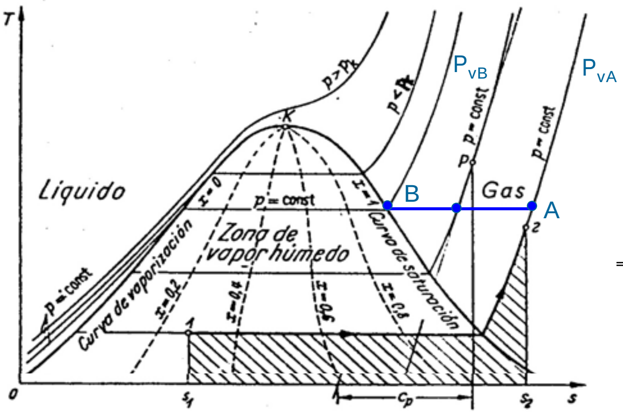
Enfriamiento a p=cte

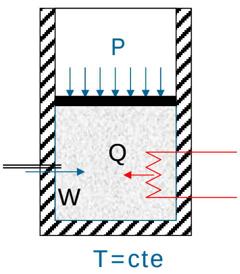
$$p_a = \frac{n_a}{n_a + n_v} . p$$

$$p_v = \frac{n_v}{n_a + n_v} . p$$

$$p = p_v + p_a$$

Humedad relativa





$$\frac{p_{vA}}{p_{vB}} = \frac{p_{v,t}}{p_{s,t}} \qquad \psi = \frac{p_{v,t}}{p_{s,t}}$$

Humedad absoluta

Es la relación entre la masa de agua y la masa de aire seco

$$x = \frac{m_w}{m_a} \qquad x = \frac{m_w}{m_a + m_w}$$

$$x = \frac{M_w}{M_a} \cdot \frac{n_w}{n_a}$$

$$x = \frac{18.02}{28.97} \cdot \frac{n_w}{n_a} = 0.622 \cdot \frac{n_w}{n_a}$$

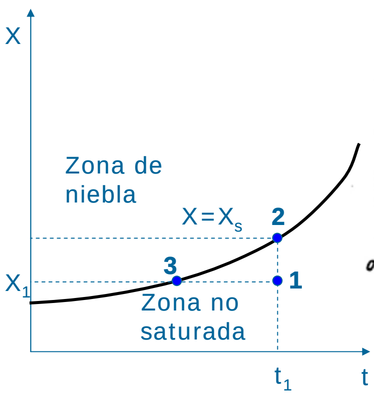
$$x = 0.622 \cdot \frac{p_v}{p_a}$$

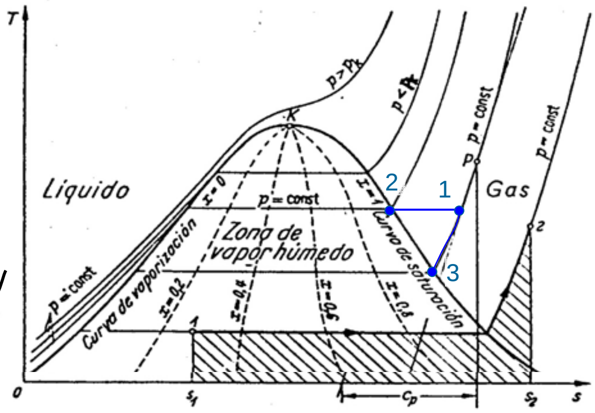
$$x = 0.622 \cdot \frac{p_v}{p - p_v}$$

Humedad absoluta

$$x_s = 0.622 \cdot \frac{p_{vs}}{p - p_{vs}}$$

$$x_s = f(t, p)$$





1-2: p=cte t=cte $p_{v2} > p_{v1}$ $x_2 > x_1$

1-3: p=cte t1>t3 p_v=cte x=cte

Grado de saturación

$$\varphi = \frac{x}{x_s}$$

$$\varphi = \frac{p_v}{p_{vs}} \cdot \frac{p - p_{vs}}{p - p_v} \qquad \psi = \frac{p_v}{p_{vs}}$$

$$\varphi = \psi \cdot \frac{p - p_{vs}}{p - p_v}$$

$$\varphi \cong \psi$$

Ecuación de estado del aire húmedo

$$p_a . v = R_a . T$$

$$p_v . v = x . R_v . T$$

$$(p_v + p_a) . v = (R_a + x . R_v) . T$$

$$p = p_a + p_v$$

$$p . v = (R_a + x . R_v) . T$$

$$R_a = 29.26 . \frac{kgr.m}{kg.K}$$

$$R_v = 47.07 . \frac{kgr.m}{kg.K}$$

Entalpía del aire húmedo no saturado

Aire seco, $h_0=0$ p/ $t_0=0°C$

$$h_a = c_{pa}.t \qquad c_{pa} = 0.24\frac{kcal}{kg.°C}$$

Agua liquida, $h_0=0$ p/ $t_0=0°C$

$$h_v = r_0 + c_{pv}.t$$

$$c_{pv} = 0.46\frac{kcal}{kg.°C} \qquad r_0 = 597\frac{kcal}{kg}$$

1kg de aire seco + x kg de vapor de agua

$$h = 1h_a + x.h_v$$

$$h = c_{pa}.t + x.(r_o + c_{pv}.t) \qquad \left[\frac{kcal}{kg(as)}\right]$$

Entalpía del a.h. con niebla

1kg de aire seco + x_s kg de vapor + $(x - x_s)$ kg de agua líquida

$$h = h_a + x_s.hv + (x - x_s).h_1$$

$$h_1 = c_1.t$$

$$h = c_{pa}.t + x_s.(r_o + c_{pv}.t) + (x - x_s).c_1.t \qquad \left[\frac{kcal}{kg(as)}\right]$$

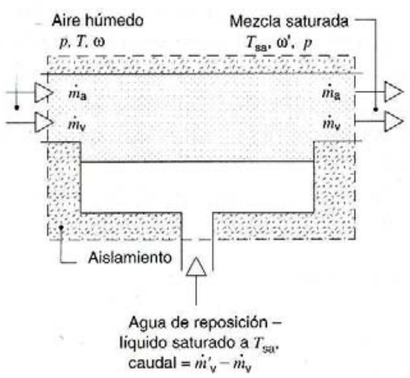
1kg de aire seco + x kg de vapor + $(x - x_s)$ kg de hielo

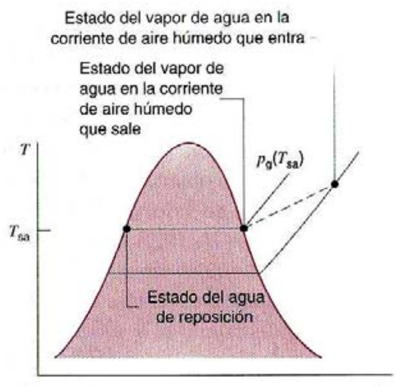
$$h = h_a + x_s.h_v + (x - x_s)h_h$$

$$h_h = -f + c_{ph}.t$$

$$h = c_{pa}.t + x_s.(r_o + c_{pv}.t) + (x - x_s).(-f + c_{ph}.t)$$

Temperatura de saturación adiabática





$h + (x_s - x).h_w = h_s$ $\quad h >> (x_s - x).h_w$ $\quad h \cong h_s$

$$c_{pa}.t + x.(r_o + c_{pv}.t) + (x_s - x).c_{pw}.t_s = c_{pa}.t_s + x_s.(r_o + c_{pv}.t_s)$$

Temperatura de saturación adiabática

$$c_{pa}.t + x.(r_o + c_{pv}.t) + (x_s - x).c_{pw}.t_s = c_{pa}.t_s + x_s.(r_o + c_{pv}.t_s)$$

$$c_{pa}.t + x.r_o + x.c_{pv}.t + (x_s - x).c_{pw}.t_s =$$

$$= c_{pa}.t_s + (x_s - x).(r_o + c_{pv}.t_s) + x.(r_o + c_{pv}.t_s)$$

$$(c_{pa} + x.c_{pv}).t = (x_s - x).(r_o + c_{pv}.t_s - c_{pw}.t_s) + (c_{pa} + x.c_{pv}).t_s$$

$c_{pa} >> x.c_{pv}$ $\quad r_o + c_{pv}.t_s - c_{pw}.t_s = h'' - h' = r$

$$c_{pa}.t = (x_s - x).r + c_{pa}.t_s$$

$$t_s = t - \frac{(x_s - x).r}{c_{pa}}$$

Temperatura de saturación adiabática

$$h \cong h_s$$

$$c_{pa}.t + x.(r_o + c_{pv}.t) = c_{pa}.t_s + x_s.(r_o + c_{pv}.t_s)$$

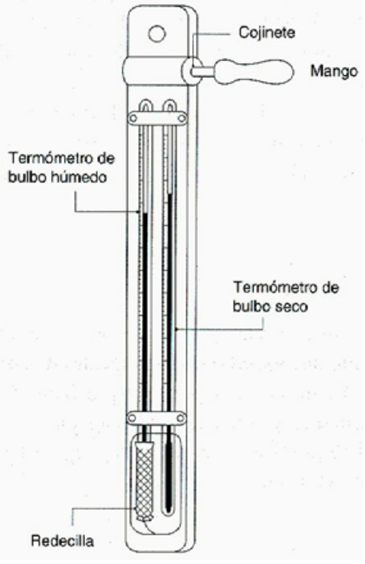
$$c_{pa}.t + x.r_o + x.c_{pv}.t = c_{pa}.t_s + x_s.r_o + x_s.c_{pv}.t_s$$

$$(c_{pa} + x.c_{pv}).t + x.r_o = (c_{pa} + x_s.c_{pv}).t_s + x_s.r_o$$

$$c_{pa}.t + (x - x_s).r_o = c_{pa}.t_s$$

$$t_s \cong t - \frac{(x_s - x).r_o}{c_{pa}}$$

Temperatura de bulbo húmedo



Cantidad de agua q se evapora

$$dw = \sigma.F.(x_s - x).d\tau$$

$$\delta Q_1 = r.dw$$

$$\delta Q_1 = r.\sigma.F.(x_s - x).d\tau$$

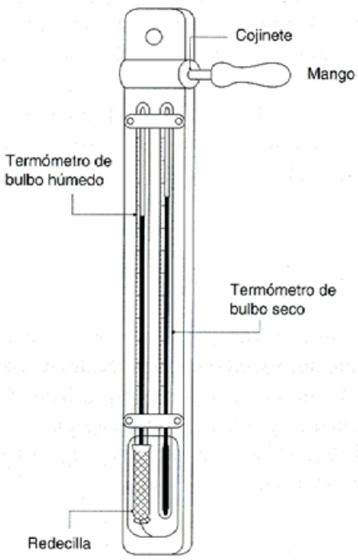
$$\delta Q_2 = k.F.(t_{bs} - t_{bh}).d\tau$$

$$r.\sigma.F.(x_s - x).d\tau = k.F.(t_{bs} - t_{bh}).d\tau$$

$$r.\sigma.(x_s - x) = k.(t_{bs} - t_{bh})$$

$$t_{bh} = t_{bs} - \frac{r.\sigma.(x_s - x)}{k}$$

Temperatura de bulbo húmedo



$$t_{bh} = t_{bs} - \frac{r.\sigma.(x_s - x)}{k}$$

$$t_s = t - \frac{(x_s - x).r}{c_{pa}}$$

$$\frac{r.\sigma}{k} = \frac{r}{c_{pa}}$$

$$\frac{c_{pa}.\sigma}{k} = 1$$ Relación de Lewis

Diagrama psicrométrico

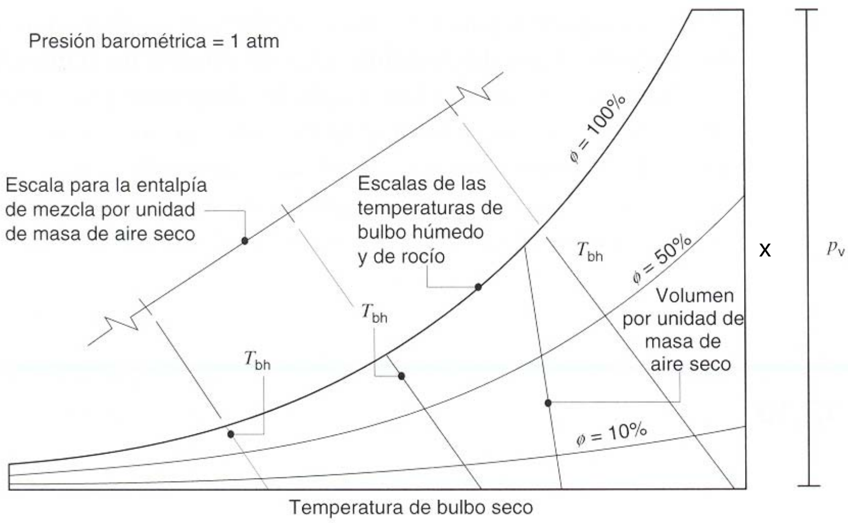
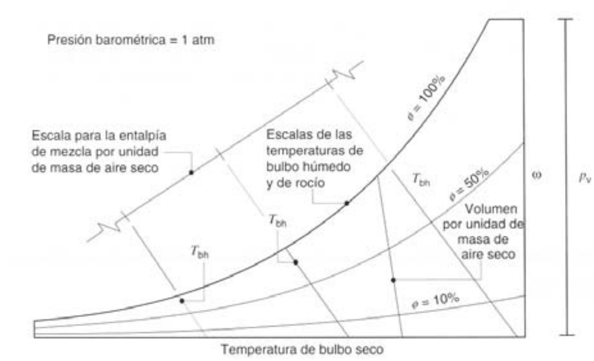


Diagrama psicrométrico



$$h = cp_a.t + x.r_0 + x.cp_v.t$$

$$dh = cp_a.dt + r_0.dx + x.cp_v.dt + cp_v.t.dx = 0$$

$$(r_0 + cp_v.t)dx = -(cp_a + x.cp_v).dt$$

$$\left(\frac{\partial x}{\partial t}\right)_{h=cte} = -\frac{cp_a + x.cp_v}{r_0 + cp_v.t}$$

$$cp_a >> x.cp_v \quad r_0 >> cp_v.t$$

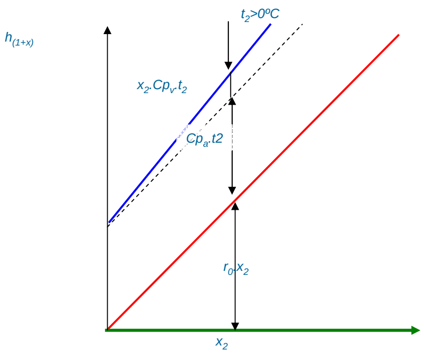
$$\left(\frac{\partial x}{\partial t}\right)_{h=cte} \cong -\frac{cp_a}{r_0}$$

$$p/_x = 0 \Rightarrow h = cp_a.t \Rightarrow t = \frac{h}{cp_a}$$

$$x_{s(t)} = 0.622.\frac{p_{vs(t)}}{p - p_{vs(t)}}$$

$$\varphi = \frac{x}{x_{s(t)}} \qquad x_{(\varphi 1,t)} = x_{s(t)}.\varphi 1$$

Diagrama entálpico



$$p/t = cte \wedge aire\ no\ saturado$$

$$h = cp_a.t + x.(r_0 + cp_v.t)$$

$$h = r_0.x + cp_a.t + x.cp_v.t$$

$$\left(\frac{\partial h}{\partial x}\right)_t = r_0 + cp_v.t$$

$$p/t = 0°C \wedge aire\ no\ saturado$$

$$h = r_0.x$$

$$\left(\frac{\partial h}{\partial x}\right)_t = r_0$$

Diagrama entálpico

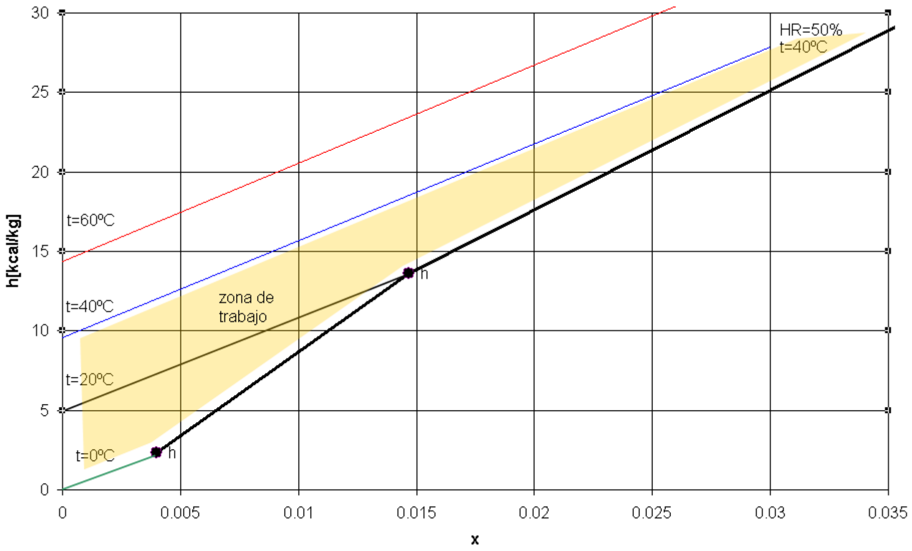
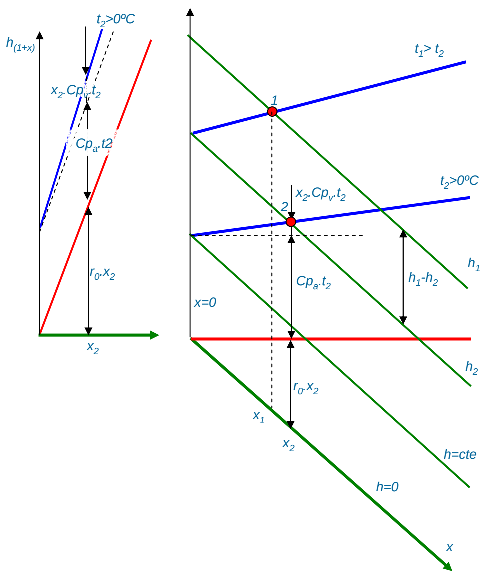


Diagrama entálpico



$$p/t = cte \wedge aire\ no\ saturado$$

$$h = cp_a.t + x.(r_0 + cp_v.t)$$

$$h = r_0.x + cp_a.t + x.cp_v.t$$

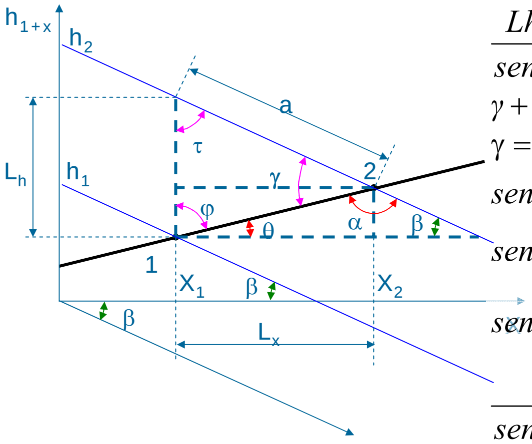
$$\left(\frac{\partial h}{\partial x}\right)_t = r_0 + cp_v.t$$

$$p/t = 0°C \wedge aire\ no\ saturado$$

$$h = r_0.x$$

$$\left(\frac{\partial h}{\partial x}\right)_t = r_0$$

Diagrama entálpico



$$\frac{Lh}{sen\gamma} = \frac{a}{sen\varphi}$$

$$\gamma + \varphi + \tau = \pi$$

$$\gamma = \pi - (\varphi + \tau)$$

$$sen\gamma = sen[\pi - (\varphi + \tau)] = sen(\varphi + \tau)$$

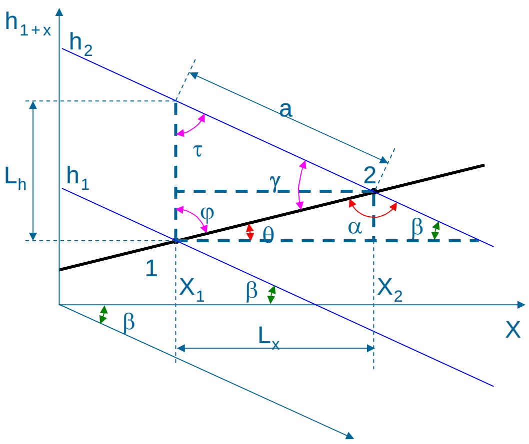
$$sen(\varphi + \tau) = sen\varphi.\cos\tau + sen\tau.\cos\varphi$$

$$sen\tau = \frac{Lx}{a} \Rightarrow a = \frac{Lx}{sen\tau}$$

$$\frac{Lh}{sen\varphi.\cos\tau + sen\tau.\cos\varphi} = \frac{Lx}{sen\tau.sen\varphi}$$

$$\frac{Lh}{Lx} = \frac{sen\varphi.\cos\tau}{sen\tau.sen\varphi} + \frac{sen\tau.\cos\varphi}{sen\tau.sen\varphi} = \cot g\tau + \cot g\varphi$$

Diagrama entálpico



$$\tau + \beta = \frac{\pi}{2} \Rightarrow \cot g\tau = tg\beta$$

$$\varphi + \theta = \frac{\pi}{2} \Rightarrow \cot g\varphi = tg\theta$$

$$\frac{Lh}{Lx} = tg\beta + tg\theta$$

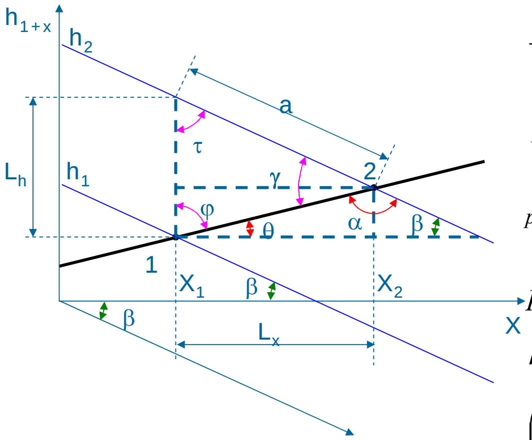
$$Lh = \frac{\Delta h}{Esc_h} \qquad Esc_h = \left[\frac{KJ}{kg.cm}\right]$$

$$Lx = \frac{\Delta x}{Esc_x} \qquad Esc_x = \left[\frac{kg_w}{kg_{as}.cm}\right]$$

$$\frac{\Delta h}{Esc_h} \cdot \frac{1}{\frac{\Delta x}{Esc_x}} = \frac{\Delta h}{\Delta x.r_{esc}} = tg\beta + tg\theta$$

$$r_{esc} = \frac{Esc_h}{Esc_x}\left[\frac{KJ}{kg}\right]$$

Diagrama entálpico



$$\frac{\Delta h}{\Delta x.r_{esc}} = tg\beta + tg\theta$$

$$p/h = cte \Rightarrow \Delta h = 0 \Rightarrow tg\theta = -tg\beta \Rightarrow \theta = -\beta$$

$$p/x = cte \Rightarrow \Delta x = 0 \Rightarrow tg\beta + tg\theta = \infty \Rightarrow \theta = \frac{\pi}{2}$$

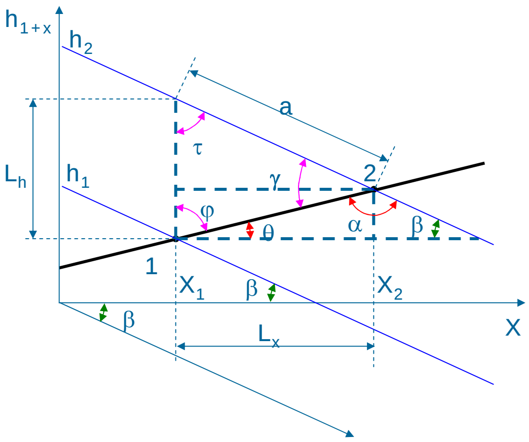
$$p/t = cte \wedge aire\ no\ saturado$$

$$h = cp_a.t + x.(r_0 + cp_v.t)$$

$$\left(\frac{\partial h}{\partial x}\right)_t = r_0 + cp_v.t$$

$$p/t = 0^o C \qquad \left(\frac{\partial h}{\partial x}\right)_t = r_0$$

Diagrama entálpico



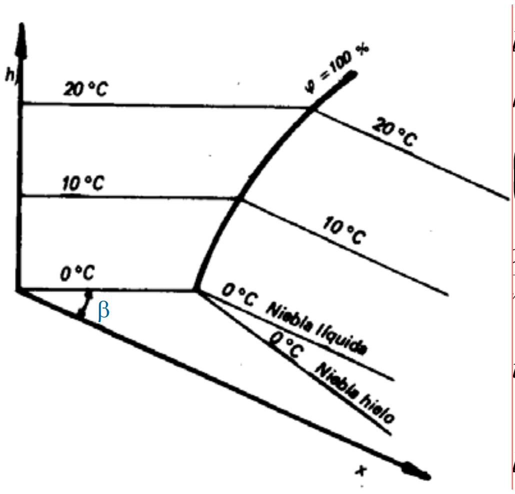
$$\frac{\Delta h}{\Delta x.r_{esc}} = tg\beta + tg\theta$$

$$\frac{r_0}{r_{esc}} = tg\beta + tg\theta$$

$$Adopto\ \ \theta = 0 \quad p/t = 0^o\mathrm{C}$$

$$tg\beta = \frac{r_0}{r_{esc}}$$

Diagrama entálpico



$$p/t = cte \wedge niebla\ líquida$$

$$h = cp_a.t + x_s(r_0 + cp_v.t) + (x - x_s).c_l.t$$

$$\left(\frac{\partial h}{\partial x}\right)_t = c_l.t$$

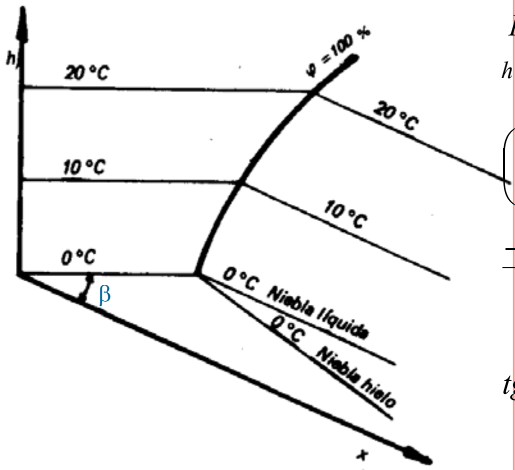
$$\frac{c_l.t}{r_{esc}} = tg\beta + tg\theta = \frac{r_0}{r_{esc}} + tg\theta$$

$$tg\theta = \frac{-r_0}{r_{esc}} + \frac{c_l.t}{r_{esc}}$$

$$p/t = 0^\circ C \wedge niebla\ líquida$$

$$tg\theta = \frac{-r_0}{r_{esc}} = -tg\beta \qquad \theta = -\beta$$

Diagrama entálpico



$$p/t = cte \wedge niebla\ hielo$$

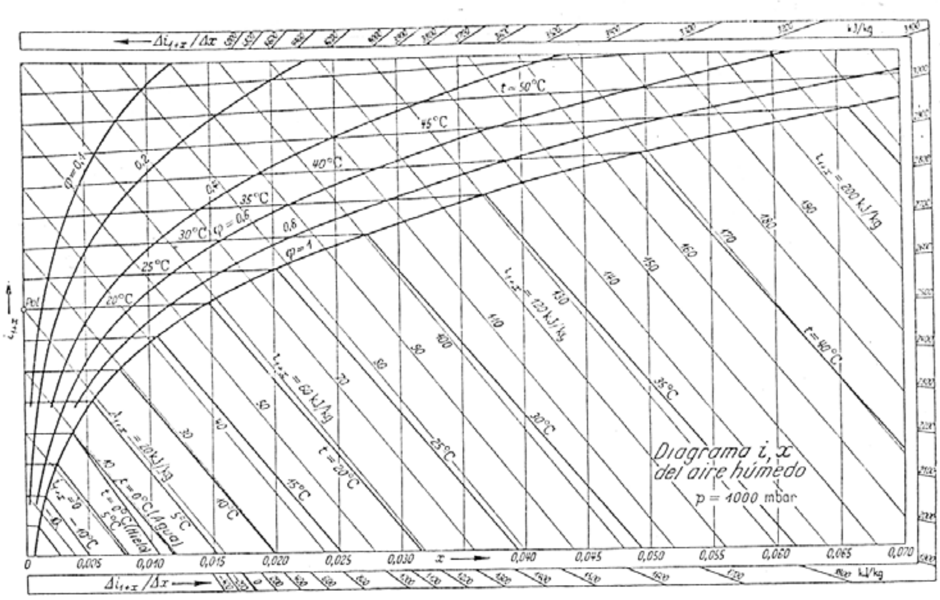
$$h = cp_a.t + x.(r_0 + cp_v.t) + (x - x_s)(-f + cp_h.t)$$

$$\left(\frac{\partial h}{\partial x}\right)_t = -f + cp_h.t$$

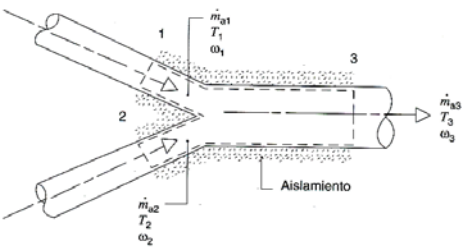
$$\frac{-f + cp_h.t}{r_{esc}} = tg\beta + tg\theta = \frac{r_0}{r_{esc}} + tg\theta$$

$$tg\theta = \frac{-r_0}{r_{esc}} + \frac{-f}{r_{esc}}$$

Diagrama entálpico



Mezcla de corrientes de a.h.



Conservación de la materia

$$m = m_1 + m_2$$

$$m.x = m_1.x_1 + m_2.x_2$$

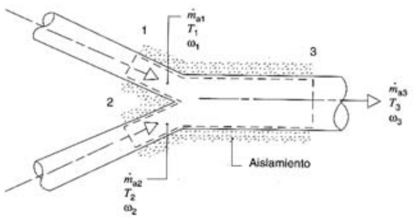
$$x = \frac{m_1.x_1 + m_2.x_2}{m_1 + m_2}$$

Conservación de la energía (PP)

$$m.h = m_1.h_1 + m_2.h_2$$

$$h = \frac{m_1.h_1 + m_2.h_2}{m_1 + m_2}$$

Mezcla de corrientes de a.h.



$$m_1.x + m_2.x = m_1.x_1 + m_2.x_2$$

$$m_2.x - m_2.x_2 = m_1.x_1 - m_1.x$$

$$m_2.(x - x_2) = m_1.(x_1 - x)$$

$$m_1.h + m_2.h = m_1.h_1 + m_2.h_2$$

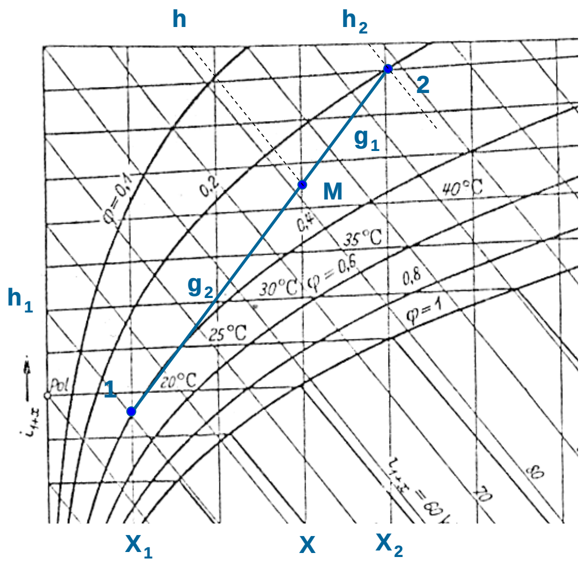
$$m_2.h - m_2.h_2 = m_1.h_1 - m_1.h$$

$$m_2.(h - h_2) = m_1.(h_1 - h)$$

$$\frac{m_2.(h - h_2)}{m_2.(x - x_2)} = \frac{m_1.(h_1 - h)}{m_1.(x_1 - x)}$$

$$\frac{h_2 - h}{x_2 - x} = \frac{h - h_1}{x - x_1}$$

Mezcla de corrientes de a.h.



$$x = \frac{m_1.x_1 + m_2.x_2}{m_1 + m_2}$$

$$g_1 = \frac{m_1}{m} \wedge g_2 = \frac{m_2}{m}$$

$$x = g_1.x_1 + g_2.x_2$$

$$g_1 + g_2 = 1$$

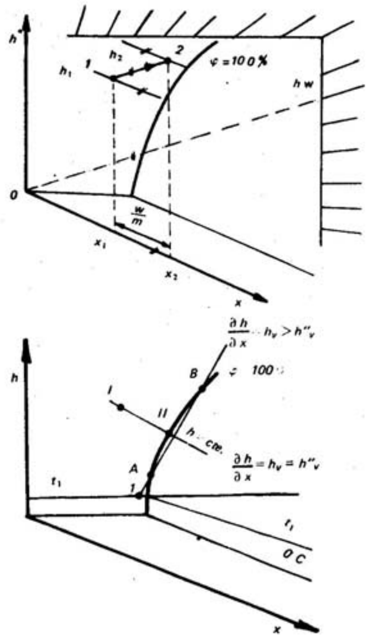
$$x = (1 - g_2).x_1 + g_2.x_2$$

$$x = x_1 - g_2.x_1 + g_2.x_2$$

$$g_2 = \frac{x - x_1}{x_2 - x_1} = \frac{\overline{1M}}{\overline{1\_2}}$$

$$\overline{1M} = \overline{1\_2}.g_2$$

Humidificación



Incorporación de agua en estado líquido o de vapor a una corriente de aire húmedo

$$m.x_1 + W = m.x_2$$

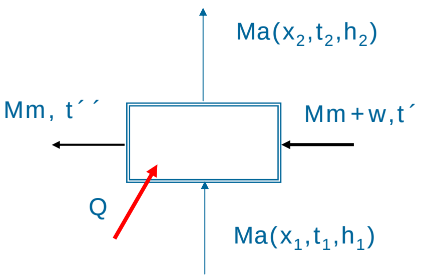
$$x_2 - x_1 = \frac{w}{m}$$

$$m.h_1 + W.h_w = m.h_2$$

$$h_2 - h_1 = \frac{W}{m} h_w$$

$$\frac{h_2 - h_1}{x_2 - x_1} = h_w$$

Secado



Material no higroscópico

$$m_a.x_1 + W = m_a.x_2$$

$$W = m_a.(x_2 - x_1)$$

$$m_a.h_1 + m_m.h_{m1} + W.h_w + Q = m_a.h_2 + m_m.h_{m2}$$

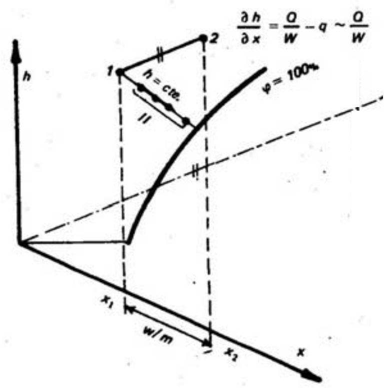
$$Q = m_a.(h_2 - h_1) + m_m.(h_{m2} - h_{m1}) - W.h_w$$

$$h_{m2} - h_{m1} = c_m (t'' - t`)$$

$$h_w = c_w.t`$$

$$Q = m_a.(h_2 - h_1) + m_m.c_m (t'' - t`) - W.c_w.t`$$

Secado



$$Q = m_a.(h_2 - h_1) + m_m.c_m(t'' - t') - W.c_w.t'$$

$$W = m_a.(x_2 - x_1)$$

$$\frac{Q}{W} = \frac{h_2 - h_1}{x_2 - x_1} + \frac{m_m.c_m}{W}(t'' - t') - c_w.t'$$

Llamando q a:

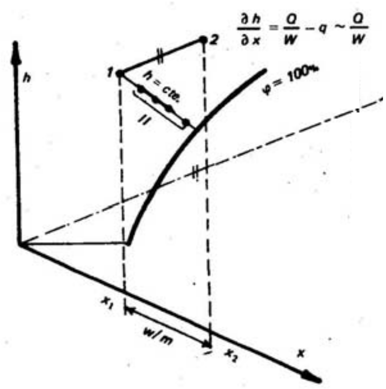
$$q = \frac{m_m.c_m}{W}(t'' - t') - c_w.t'$$

$$\frac{Q}{W} = \frac{h_2 - h_1}{x_2 - x_1} + q$$

Despreciando el valor de q

$$\frac{Q}{W} = \frac{h_2 - h_1}{x_2 - x_1}$$

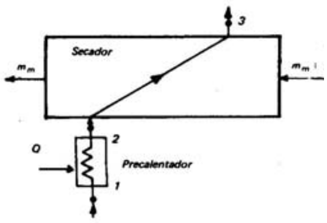
Secado

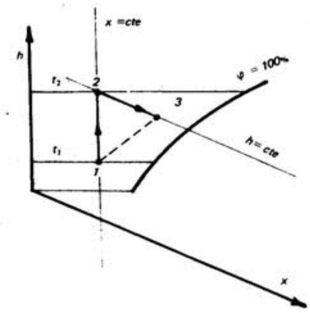


$$x_2 = x_1 + \frac{W}{m_a}$$

$$\frac{h_2 - h_1}{x_2 - x_1} = \frac{Q}{W} - q \cong \frac{Q}{W}$$

Secado con precalentador





$$m_a = \frac{W}{x_3 - x_2} = \frac{W}{x_3 - x_1}$$

$$Q = m_a\left(h_2 - h_1\right) = m_a\left(h_3 - h_1\right)$$

$$\frac{Q}{W} = \frac{h_3 - h_1}{x_3 - x_1}$$