Humid heat (air-water) Cs = (1.005 + 1.88H); SI (kJ/kg dry air), Cs = 0.24 + 0.45H; English (Btu/lb DA.°F)

Cp_w = 4,187 kJ/kgK and Latent heat = 2442 kJ/kg at 25 °C

R = - (Ls/A) (dX/dt), R = aX + b, R = aX

t= (Ls/A).∫(dX/R), $V_{avg} = Q/A$

For Re ….. Vmax = $2V_{avg}$, Minimum process time = L/V_{max}

For Re ….. Vmax = $V_{avg}/(0.0336 \log Re + 0.662)$

$$\frac{dN}{dt} = \mp k.N^n$$

F = SV * D_T, log No/N = SV 1 cP = 0.001 Pa.s

Z = ln 10 x T_1 x T_2/(Ea/R) $k_2 = k_1 10^{(T_2 - T_1)/z}$, Ea/R = [(ln Q_{10})/10]$T_1 T_2$

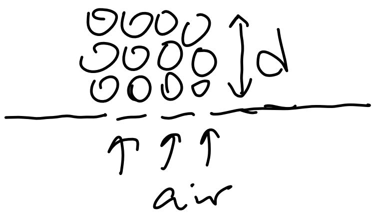
D = 2,303/k $t = D \log_{10} N_o/N$, $F_o = D_{250} \log_{10} N_o/N$

$F_o = L = t * 10^{(T-121)/z}$

$$t_F = \frac{\rho L_V}{T_F - T_\infty}\left[\frac{Pa}{h_c} + \frac{Ra^2}{k_I}\right] \qquad \log\frac{D_{ref}}{D_T} = \frac{T - T_{ref}}{z}$$

h: heat tr. coefficient

d: depth of bed



R = q/Aλ_w = h(T - T_w)/λ_w = k_y A (H_w - H)

$$t = \frac{L_S(X_1 - X_2)}{A(R_1 - R_2)} \ln\frac{R_1}{R_2}$$

$$t_c = \frac{\rho_s \times \lambda_w \times d \times (X_1 - X_c)}{(T - T_{wb}) \times h}$$

$$t = \frac{L_S X_C}{A R_C} \ln\frac{X_C}{X_2}$$

$$t_f = \frac{\rho_s \times \lambda_w \times d \times (X_c - X_e)}{(T - T_{wb}) \times h} \times \ln\left[\frac{X_c - X_e}{X_2 - X_e}\right]$$

Ts

$$t = \frac{L_S}{A}\int_{X_2}^{X_1} \frac{dX}{R}$$

R = - (Ls/A) (dX/dt),

h = $0.0204G^{0.8}$ (air is flowing parallel to the drying surface) (SI)

h = $0.0128G^{0.8}$ (air is flowing parallel to the drying surface) (British)

h = 1.17 $G^{0.37}$ (air is flowing perpendicular to the drying surface) (SI)

h = 0.37 $G^{0.37}$ (air is flowing perpendicular to the drying surface) (English)

t = Ls.λ_w (X_1-X_2)/[A.h.(T-T_w)] = Ls.(X_1-X_2)/[A.k.M_B(H_w-H)]

G = v.ρ 1 ft = 30.48 cm, 1 lbm = 0.45 kg, 1 inch = 2.54 cm

Infinite slabs: P = 1/2 , R = 1/8

Infinite cylinder: P = 1/4 , R = 1/16

Sphere : P = 1/6 , R = 1/24

$$t = \frac{L_s \times \rho \times (X_0 - X_f)}{k \times (T_s - T_f)} \times \frac{L^2}{2} \; ; \; t = \frac{\rho \times (X_0 - \overset{X_e}{X_f}) \times \frac{L^2}{2}}{b \times (P_i - P_D)}$$

$$\frac{1}{D} = \frac{\log N_0 - \log N_f}{t}$$

$$\boxed{D = \frac{t}{\log \frac{N_0}{N_f}}} \Rightarrow \boxed{t = D \times \log \frac{N_0}{N_f}}$$

$$\boxed{\log \frac{N_0}{N_f} = \frac{t}{D}} \Rightarrow \boxed{\frac{N_0}{N_f} = 10^{t/D}}$$

$$\boxed{z = \frac{T_2 - T_1}{\log D_1 - \log D_2}}$$

$$\log \frac{D_1}{D_2} = \frac{T_2 - T_1}{z} \Rightarrow \boxed{\frac{D_1}{D_2} = 10^{\frac{T_2 - T_1}{z}}}$$

If $T_2 = T_{ref} = T_0 \Rightarrow D_2 = D_{ref} = D_0$, then

$$D = D_0 \times 10^{[(T_0 - T)/z]}, \quad F_0 = \underset{t}{F} \times 10^{[(T - T_0)/z]}$$

$$\boxed{\frac{1}{r} = \frac{No}{10^{F/D}}}$$

Pham's empirical equation :

$T_{fm} = 1.8 + 0.263xT_c + 0.105xT_a$, here $T_a = T_\infty$

$\Delta H_1 = \rho_u \times C_{pu} \times (T_i - T_{fm})$

$\Delta H_2 = \rho_f \times [L_f + C_{pf} \times (T_{fm} - T_c)]$

$$\Delta T_1 = \frac{T_i + T_{fm}}{2} - T_a$$

$$\Delta T_2 = T_{fm} - T_a$$

$$t_f = \frac{d_c}{E_f \times h_c} x[\frac{\Delta H_1}{\Delta T_1} + \frac{\Delta H_2}{\Delta T_2}]x(1 + \frac{N_{Bi}}{2})$$

d_c : characteristic dimension of the object being frozen.

- **For cylinder and sphere it is radius**
- **For slab it is half thickness.**

h_c : convective heat transfer coefficient ($W/m^2.K.°C$)
E_f : shape factor.
E_f is 1 for infinite slab, 2 for infinite cylinder and 3 for infinite sphere.

- **For complicated shapes, E_f must be determined**

$$N_{Bi} = \frac{h_c \times d_c}{k} = \frac{\text{heat convection resistance}}{\text{heat conduction resistance}}$$

$$q = \frac{a.e^{b.T_1}}{\left(\frac{T_1 - T_2}{t}\right).b}[1 - e^{-b.(T_1 - T_2)}]$$

$$Q10 = (R2/R1)^{10/(T2-T1)}$$