

$$V_{avg} = \frac{Q}{A}$$

$$\text{For Re } \dots \quad V_{max} = 2 \cdot V_{avg} \quad ; \quad \text{For Re } \dots \quad V_{max} = \frac{V_{avg}}{(0.0336 \times \log Re + 0.662)}$$

$$Re = \frac{\rho \cdot V_{avg} \cdot D}{\mu}$$

$$\text{Minimum process time} = \frac{L}{V_{max}}$$

$$\frac{1}{D} = \frac{\log N_0 - \log N_f}{t} \quad ; \quad D = \frac{t}{\log\left(\frac{N_0}{N_f}\right)} \quad ; \quad \frac{N_0}{N_f} = 10^{\left(\frac{t}{D}\right)}$$

$$F = SV \cdot D_T \quad ; \quad SV = \log\left(\frac{N_0}{N}\right) \quad ; \quad F_0 = L = t \cdot 10^{\left[\frac{(T-121)}{z}\right]} \quad ; \quad F_0 = D_{250} \cdot \log\left(\frac{N_0}{N}\right)$$

$$t = D \cdot \log\left(\frac{N_0}{N}\right) \quad ; \quad D = \frac{2.303}{k} \quad ; \quad \log\left(\frac{D_{ref}}{D_T}\right) = \frac{T - T_{ref}}{z} \quad ; \quad z = \frac{T_2 - T_1}{\log D_1 - \log D_2} \quad ; \quad \frac{D_1}{D_2} = 10^{\left(\frac{T_2 - T_1}{z}\right)}$$

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

$$D = D_0 \cdot 10^{\left[\frac{(T_0 - T)}{z}\right]} \quad ; \quad F_0 = F \cdot 10^{\left[\frac{(T - T_0)}{z}\right]}$$

$$\log\left(\frac{k_2}{k_1}\right) = \log\left(\frac{D_1}{D_2}\right) = \log 10^{\left(\frac{T_2 - T_1}{z}\right)} \quad ; \quad \log\left(\frac{k_2}{k_1}\right) = \frac{E_a}{2.303 \cdot R} \left[\frac{1}{T_1} - \frac{1}{T_2}\right] \quad ; \quad E_a = \frac{2.303 \cdot R}{z} (T_1 \cdot T_2)$$

$$Q_{10} = \frac{D_1}{D_2} = 10^{\left[\frac{(T_2 - T_1)}{z}\right]} = 10^{\left(\frac{10}{z}\right)} \quad ; \quad \frac{dN}{dt} = \pm k \cdot N^n \quad ; \quad \frac{1}{r} = \frac{N_0}{10^{\left(\frac{F}{D}\right)}}$$

Humid heat (air-water) $C_s = (1.005 + 1.88xH)$; SI (kJ/kg DA), DA : dry air

$$C_s = 0.24 + 0.45xH; \text{ English (Btu/lb DA} \cdot \text{ }^\circ\text{F)}$$

$$V_H = (2.83 \times 10^{-3} + 4.56 \times 10^{-3} xH) \cdot T \quad \text{where } T \text{ is in K in SI system}$$

$$R = -\left(\frac{L_s}{A}\right) \left(\frac{dX}{dt}\right),$$

$$R = a \cdot X + b,$$

$$R = a \cdot X$$

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

$$t = \frac{L_s \cdot (X_1 - X_2)}{A \cdot (R_1 - R_2)} \ln\left(\frac{R_1}{R_2}\right)$$

$$t = \frac{L_s \cdot X_c}{A \cdot R_c} \ln \frac{X_c}{X_2}$$

$$R = \frac{q}{A \cdot \lambda_w} = \frac{h \cdot (T - T_w)}{\lambda_w} = k_y \cdot A \cdot (H_w - H)$$

$$t_c = \frac{L_s}{A \cdot R_c} (X_1 - X_2) ; R_c = \frac{L_s}{A \cdot t_c} (X_1 - X_2)$$

$$t_c = \frac{L_s \cdot \lambda_w \cdot (X_1 - X_2)}{A \cdot h \cdot (T - T_{wb})} = \frac{L_s \cdot (X_1 - X_2)}{A \cdot k_y \cdot M_B \cdot (H_w - H)}$$

M_B is molecular weight of air, $H_w = H_s$

$h = 0.0204G^{0.8}$ (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)

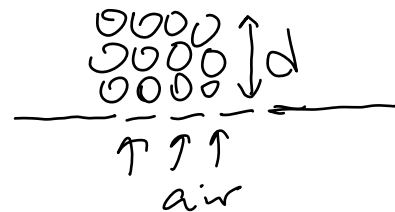
$$G = v \cdot \rho$$

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

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

h : heat tr. coefficient

d : depth of bed



$$t = \frac{L_s \cdot \rho \cdot (X_0 - X_f)}{k \cdot (T_s - T_f)} \times \frac{L^2}{2} ;$$

$$t = \frac{\rho \cdot (X_0 - X_f) \cdot \frac{L^2}{2}}{b \cdot (P_i - P_d)}$$

$$t_F = \frac{\rho \cdot L_v}{T_F - T_\infty} \left[\frac{P \cdot a}{h_c} + \frac{R \cdot a^2}{k_I} \right]$$

**a: the thickness of slab; diameter of the sphere; diameter of infinite cylinder.
P and R are the geometric constants for different shapes of objects used in deriving Plank's equation.**

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

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

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

$$T_{fm} = 1.8 + 0.263 \times T_c + 0.105 \times T_a, \text{ here } T_a = T_\infty$$

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

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

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

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

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

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/m².K.°C)

E_r : shape factor.

E_r is 1 for infinite slab, 2 for infinite cylinder and 3 for infinite sphere.

❖ For complicated shapes, E_r must be determined

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

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

$$Q_{10} = \left(\frac{R_2}{R_1} \right)^{\left[\frac{10}{(T_2 - T_1)} \right]}$$

1 cP = 0.001 Pa.s; 1 ft = 30.48 cm; 1 lb_m = 0.45 kg; 1 inch = 2.54 cm

C_{p,w} = 4,187 kJ/kg.K and Latent heat = 2442 kJ/kg at 25°C