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

For Re ….. $V_{max} = 2.V_{avg}$; For Re ….. $V_{max} = \frac{V_{avg}}{(0.0336xlogR_e + 0.662)}$

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

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

$$\frac{1}{D} = \frac{logN_0 - logN_f}{t} \quad ; \quad D = \frac{t}{\log(\frac{N_0}{N_f})} \quad ; \quad \frac{N_0}{N_f} = 10^{(\frac{t}{D})}$$

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

$$t = D.\log\left(\frac{N_0}{N}\right) ; \ D = \frac{2.303}{k} \ ; \ \log\left(\frac{D_{ref}}{D_T}\right) = \frac{T - T_{ref}}{z} ; \ z = \frac{T_2 - T_1}{logD_1 - logD_2} ; \ \frac{D_1}{D_2} = 10^{\left(\frac{T_2 - T_1}{z}\right)}$$

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

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

t

$$\log\left(\frac{k_2}{k_1}\right) = \log\left(\frac{D_1}{D_2}\right) = log10^{(\frac{T_2 - T_1}{z})} \ ; \log\left(\frac{k_2}{k_1}\right) = \frac{E_a}{2.303.R}\left[\frac{1}{T_1} - \frac{1}{T_2}\right] ; \ E_a = \frac{2.303xR}{z}(T_1.T_2)$$

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

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

Cs = 0.24 + 0.45xH; English (Btu/lb DA.°F)

$$V_H = (2.83x10^{-3} + 4.56x10^{-3}xH).T \quad where\ T\ is\ in\ K\ in\ SI\ system$$

$R = -\left(\frac{L_S}{A}\right)\left(\frac{dX}{dt}\right)$, R = a.X + b, R = a.X

$$t = \frac{L_S}{A}\int_{X_2}^{X_1}\frac{dX}{R} \qquad t = \frac{L_S.(X_1 - X_2)}{A.(R_1 - R_2)}\ln\left(\frac{R_1}{R_2}\right) \qquad t = \frac{L_S.X_c}{A.R_c}\ln\frac{X_c}{X_2}$$

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

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

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

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)

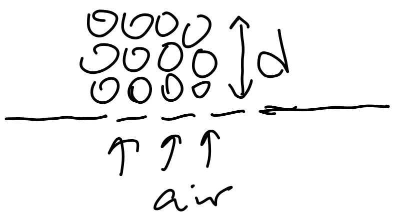
G = v.ρ

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

h: heat tr. coefficient

d: depth of bed

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



$$t = \frac{L_s.\rho.(X_0 - X_f)}{k.(T_s - T_f)} x \frac{L^2}{2} \;; \qquad t = \frac{\rho.\left(X_0 - X_f\right).\frac{L^2}{2}}{b.(P_i - P_d)}$$

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

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

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

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

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

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

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

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

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_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**

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

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

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

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

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