# # Food.processing Engineering (Notes) #

① Temperature inside sphere

$\ln\left(\frac{T_\infty - T}{T_\infty - T_i}\right) = -\frac{h \times A \times t}{\rho \times V \times C_p}$ time

$T_i$ = initial temp

② Prandtl No. = $\frac{\mu C_p}{k}$ , $\boxed{\text{Nusselt No.} = \frac{hD}{k}}$

③ Biot No → $B_i = \frac{hL}{K}$

$\boxed{Nu = 0.023\, Re^{0.8} (Pr)^n}$

n = 0.4 → heated condition

n = 0.3 → cold condition

④ Food grains are sometimes subjected to hydrothermal treatment prior to milling called conditioning

⑤ milling relates → size reduction and separation operation.

⑥ The velocity of the particles at any point on the inclined plane

$\boxed{V_1 = \sqrt{2 g k_1 x_1}}$

$k_1 = \sin\alpha - \mu_1 \cos\alpha$

$x_1$ = distance travelled by body.

higher velocity

$v_0 = v_1 (1 + k_2/k_1)$

$v_0$ = absolute velocity of the upper layer.

$v_0 > v_1$ $k_2/k_1$

→ ① free flow particle can be used.

② separation of husked and unhusked grain

⑦ husking → the removal of outer seed coat from the grain kernel

Note: term hulling and scouring are also used in cereal milling.

⑧ $St = \frac{Nu}{Re \times Pr}$

Stanton No. = $\frac{h}{\rho C_p}$

mean velocity $v$

⑨ Grashoff No. = $\frac{g\beta (T_s - T_a)\rho^2}{\mu^2}$

$\beta = \frac{1}{(T_f + 273)}$

⑨ heat transfer from a fin

$\boxed{q = KAm(T_0 - T_a) \tanh(m \times L_c)}$

⑩ equation centre temperature $T_0$

cylinder → $\boxed{T_0 = \frac{qr^2}{4k} + T_w}$

plane → $\boxed{T_0 - T_w = \frac{qL^2}{2k}}$

⑪ (a) $Nu = 0.664 \times Re^{0.5} Pr^{0.33}$ ($Re < 3 \times 10^5$, $Pr > 0.7$).

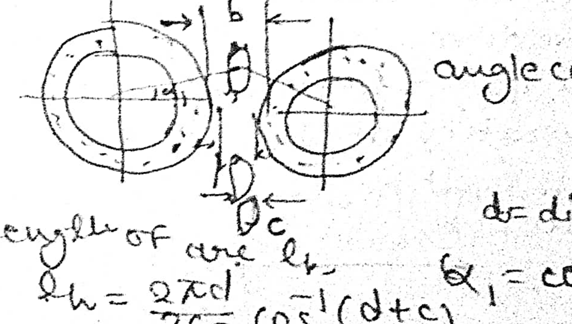
(b) $Nu = 0.023\, Re^{0.8} Pr^{0.33}$ → turbulent flow.

⑫ effectiveness of the separation.

rubber roll sheller

$E_A = \frac{(x_F - x_D)\, x_C (x_F - x_C)(1 - x_D)}{(x_D - x_C)^2\, x_F (1 - x_F)}$

⑬



angle $\cos\alpha_1 = \frac{r + c/2}{r + b/2}$

$= \frac{d + c}{d + b}$

d = dia. of the

$\alpha_1 = \cos^{-1}\left(\frac{d}{d}\right.$

length of arc $l_h$

$l_h = \frac{2\pi d}{360} \cos^{-1}\left(\frac{d+c}{d+b}\right)$

(14) $S_{ad} = \frac{[illegible](V_f - V_s)}{V_f}$

$S_{ad}$ = difference b/w the speeds of faster and slower roll. →

$V_f$ = 15 to 17.5 m/s

$V_s$ = 12.5 to 15 m/s

$V_f - V_s$ = should not be less than 2.5 m/sec.

Period of husking

$t = \left(\frac{g_c}{V_f}\right)$ (faster roll)

$t = \left(\frac{g_c - S_{ad}}{V_s}\right)$ (slower roll)

(15) Effectiveness of hulling

$E_{hulling} = \left(\frac{W_1 - W_2}{W_1}\right) = \left(1 - \frac{W_2}{W_1}\right)$

$W_1$ = amount of paddy before hulling

$W_2$ = — " — unhulled after hulling.

(16) Theoretical capacity of a pair of mill can be determined

$Q_T = 3.6 \times \rho \times D \times v_g \times b \times \psi$

$\psi = \frac{Q_a}{Q_T}$ = actual capacity % of mill [illegible]

$V_g$ = velocity of [illegible]

b = clearance b/w the rolls [illegible]

(17) Hydrothermal treatment → the addition of moisture and heat to the grain for improving the quality and quantity of their end product.

# Hydrothermal treatment is commonly called conditioning.

(18) The fat and oils are composed of different mixture of glycerides of various fatty acid.

(ii) The waxes are mixtures of higher polyhydric alcohols with fatty acid (other than glycerol)

(19) Theoretical capacity of bucket elevators (kg/h)

C = capacity of a bucket

$10^3$ × no. of bucket × density lifted per second

volume of a bucket $= \frac{r^2\theta}{2}$

θ = angle subtended

(20) Horse power :-

$HP = \frac{K \times C \times L}{75}$

L = lift of elevator (m), C = capacity kg/s

K = factor 1.2 to 1.5

(1.2 → loaded on the bottom side,

1.5 → loaded on the upside).

(21) Screw conveyor :

(i) theoretical capacity

$$\boxed{C = \frac{\pi}{4}(D^2 - d^2)\rho \times N \times P}$$

P = pitch (m)

D = screw dia. (m)

d = shaft dia. (m)

N = revolution

ρ = density kg/m³

ⓐ Rankine's theory

$P_e = \omega \times h \times k = \omega \times h \times \left(\frac{1-\sin\theta}{1+\sin\theta}\right)$

$k = \frac{\text{lateral pressure}}{\text{vertical pressure}} = \frac{P_e}{P_v} = \frac{1-\sin\theta}{1+\sin\theta}$

ⓑ **Airy theory for shallow bin :-**

$$P_e = \omega \times h \times \left[\frac{1}{\sqrt{\mu(\mu+\mu')} + \sqrt{1+\mu^2}}\right]^2$$

$\mu$ = cofficient of friction of grain
tan θi = θi internal friction

$\mu'$ = tan θw, the angle of wall friction.

→ shallow bin → $h < L \tan\left(\frac{90+\phi'}{2}\right) \rightarrow h \leq 4R$

→ deep bin → $h > L \tan\left(\frac{90+\phi'}{2}\right) \rightarrow h > 4R$

Jensen theory for deep bin

$$P_e = \frac{\omega \times R}{\mu}\left[1 - e^{-\frac{\mu \times k \times h}{R}}\right]$$

ω = grain bulk density
R = hydraulic Radius
h = depth of grain. $k = P_e/P_v$

(22) % Saturation = $RH\left(\frac{P - P_s}{P - P_v}\right) \times 100$

Imp

(23) Carrier's equation

$$P_w = P_s - \frac{(P - P_s)(T_b - T_w)}{1500 - 1.44\,T_w}$$

(24) problem in Rice bran processing.

ⓐ rapid hydrolysis of oil into FFA and glycerol.

(25) Time of cooling and Heating of liquid

Imp

$t_c = \frac{mc_p}{UA} \ln\left(\frac{T_i - T_c}{T_f - T_c}\right)$ where $t_c$ is cooling time.

$t_h = \frac{mc_p}{UA} \ln\left(\frac{T_h - T_i}{T_h - T_f}\right)$ $T_i$ = initial temp. °c

where $t_h$ is heating time,

$T_c$ = tem of cooling medium temp. °c

(26) $$\boxed{\frac{1}{U} = \frac{1}{h} + \frac{r_1}{k}}$$

(27) Heat conduction Through A Hollow sphere :-

$$q = \frac{(T_1 - T_2)}{\frac{1}{4\pi k}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)} \text{ or}$$

$$= \frac{4\pi k r_1 r_2 (T_1 - T_2)}{(r_2 - r_1)}$$

(28) Critical Radius of Insulation

ⓐ cylindrical system = $r_c = \frac{k}{h_o}$

ⓑ spherical system $r_c = \frac{2k}{h_o}$

(29) Lumped system analysis. equation

$$\boxed{\ln\left(\frac{T_m - T}{T_m - T_0}\right) = -\frac{hAt}{V \times \rho \times C_p}}$$

$T_m$ = cooling or heating medium

T = final temp°c $T_0$ = initial temperature

(30) Hollow cylinder / overall heat transfer coefficient:-

$$\vartheta = 2\pi KL\frac{(T_1-T_2)}{\ln(r_2/r_1)}$$

$$\frac{1}{U} = \frac{1}{h_i} + \frac{r_i \ln(r_2/r_1)}{K_1} + \frac{\ln(\cancel{r_2/r_1})}{k_2} + \frac{1}{h_0}\times\frac{r_1}{r_2}$$

SI unit of heat transfer cofficient is $w/m^2k$.

(31) $N_A$ (diffusion flux)

$$= \frac{P_M(P_{A_1}-P_{A_2})}{22.414(Z_2-Z_1)}$$

(32) Water vapour permeability cofficient

$$\boxed{P_{w,v} = \frac{\dot m \times x}{A\times\Delta P}}$$

$\dot m$ = Rate of water vapour transfer

Size-reduction:-

(33) Kick's Law:-

$$\boxed{E = K_K \ln\frac{x_f}{x_p}}, \quad \frac{P}{f} = K_K \ln\left(\frac{x_f}{x_p}\right)$$

$K_K$ = Kick constant

$x_f$ = average initial size of feed particles, m

$x_p$ = average size of product particles, m.

(34): Rittinger's law:-

$$\boxed{E = K_R\left(\frac{1}{x_p}-\frac{1}{x_f}\right).} \text{ or } \frac{P}{f} = K_R\left(\frac{1}{x_p}-\frac{1}{x_f}\right).$$

(35) Bond's law:-

$$E = 2K_B\left(\frac{1}{\sqrt{x_p}}-\frac{1}{\sqrt{x_f}}\right) \text{ or } \frac{P}{f} = 2K_B\left(\frac{1}{\sqrt{x_p}}-\frac{1}{\sqrt{x_f}}\right).$$

The energy required for size reduction by Bond's law may also be predicated by the expression.

$$E = 0.3162\, W_i\left(\frac{1}{\sqrt{D_p}}-\frac{1}{\sqrt{D_f}}\right) \text{ or.}$$

$$\frac{P}{f} = 0.3162\, W_i\left(\frac{1}{\sqrt{D_p}}-\frac{1}{\sqrt{D_f}}\right).$$

$f$ = feed rate t/h

$W_i$ = bond work index,

$D_p$ = 80% of product pass through Mesh of dia. $D_p$, mm

$D_f$ = 80% of feed passes through Mesh of dia. $D_f$, mm.

$P$ = Power kW,

(36) critical speed of Ball

$$n_c = \frac{1}{2\pi}\sqrt{g/R-r}$$

$n_c$ = speed rps

$R$ = radius of cylinder (m)

$r$ = radius of ball m

(37) crushing Rolls.

$$\cos\alpha/2 = \frac{D_r+D_p}{D_r+D_f}$$

$D_r$ = dia. of roll

$D_f$ = dia of feed

$D_p$ = avg. dia of product

(38) Angle of Nip:-

$$\mu = \tan\left(\frac{\alpha}{2}\right)$$

(39) capacity of crushing Roll:-

$$\vartheta = \pi D_r \times N \times D_p \times L \qquad \vartheta = m^3/s.$$

$D_r$ = roll dia. (m)

$D_p$ = is nip (m).

$N$ = roll speed (rps).

# peripheral velocity of roll (m/s):-

$$V = \pi D_r N$$

# mass flow rate:-

$$\dot m = \vartheta \times \rho \text{ kg/s.}$$

$\rho$ = bulk density of product kg/m³

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Degree of Grinding :-

$$d_g = \frac{S_P}{S_f}$$

$S_P$ = overall surface area of product m²

$S_f$ = surface area of feed m²

The increase in temp during homogenization in following liquid having a density of $\rho$ (kg/m³)

$$\boxed{\Delta T = \frac{P}{\rho \times C_P}} \; °C$$ → pressure (Pa).

# Power consumption in Homogenization

$$P_0 = \mathcal{G} P$$

where $P_0$ is in W and $\mathcal{G}$ is volumetric flow rate (m³/s), P = pressure (Pa)

Imp

Power consumption in Liquid Mixing :-

Power no. $P_0 = \frac{P}{\rho \times N^3 D^5}$, $Re = \frac{\rho \times N \times D^2}{\mu}$

Froude No $Fr = \frac{N^2 D}{g}$.

D = dia of impeller

N = rotational speed rps

$\mu$ = viscosity of liquid (Pa S)

# Cleaning efficiency $= \frac{E(F-G)(E-F)(1-G)}{F(E-G)^2(1-F)}$.

E = fraction of clean grain at clean grain outlet.

F = fraction of clean grain in feed.

G = fraction of clean grain at ~~fore~~ foreign matter outlet.

Mixing : (Power consumption in Liquid Mixing

Power no. $P_0 = \frac{P}{\rho \times N^3 \times D^5}$ Froude No. $= \frac{N^2 D}{g}$

Imp Mixing index(M) :- $\boxed{M = \frac{S_0^2 - S^2}{S_0^2 - S_r^2}}$

$S^2$ = variance of distribution of a given constituent

$S_0^2$ = initial variance

$S_r^2$ = variance for a stochastically mixing product

Imp :Rate of Mixing :-

$$\boxed{1 - M = e^{-kt}}$$

average particles size of wheat flour.

$$\boxed{D_p = 0.104 (2)^{FM}}$$

effectiveness of sepration in % :

$$= \frac{(m_f - m_u)(m_0 - m_f)(1 - m_u)\, m_0}{(m_0 - m_u)^2 (1 - m_f)\, m_f}$$

Fick law for Molecular diffusion.

$$\boxed{N_{Az} = - D_{AB} \times \frac{dC_A}{dz}}$$

$N_{Az}$ = molar flux of component A in z direction kg mole/m²s.

$D_{AB}$ = molecular diffusivity of molecule A in B m²/s

$C_A$ = Concentration of A kg mole/m³

z = distance along direction

$$\boxed{C_A = P_A/RT}$$

relationship b/w heat transfer coefficient and $D_{AB}$

$$\frac{h}{K_C} = \rho \times C_p \times \left(\frac{\alpha}{D_{AB}}\right)^{3/2}$$

→ Mass trafer

nvective Mass Transfer coefficient :-

$N_A = k_c (C_{A1} - C_{A2})$.

$N_A$ = molar flux of component A, kg mole/(s.m$^2$)

$k_c$ = convective mass transfer coefficient m/s.

Schmidt number (Sc) : - is equivalent to prandtl no. in heat transfer

Mathematically

$Sc = \frac{\nu}{D_{AB}} = \frac{\mu}{\rho \times D_{AB}}$ ⇒ $\mu$ = fluid viscosity, Pa.s

$\rho$ = fluid density, kg/m$^3$

ⓑ Sherwood Number : - is equivalent to Nusselt number! -

$Sh = \frac{K_c \times D}{D_{AB}}$, $k_c$ = mass transfer, m/s

D = characteristics dimension, m.

$D_{AB}$ = diffusion coefficient m$^2$/s.

ⓒ Lewis Number :

$Le = \frac{\alpha}{D_{AB}} = \frac{k}{\rho \times c_p \times D_{AB}}$ $\left[\alpha = \frac{k}{\rho \times c_p}\right]$

New topic

① Rate of filtration : -

$q = \frac{dv}{dt} = \frac{\overset{m^2}{A} \times \Delta P}{\underset{\downarrow Pa.s}{\mu} R} \begin{matrix} \to Pa \\ \to m^{-1} \end{matrix}$ [The basic law of fluid flow through porous media is known as, Darcy law]

② centrifugal filtration.

$$\boxed{(m^3/s)\, q = \frac{\rho \omega^2 (r_2^2 - r_1^2)}{2\mu \left(\frac{m_c \alpha}{A^2} + \frac{R_m}{A}\right)}}$$

$r_1$ = inner radius of liquid surface

$r_2$ = inside radius of basket

③ settling and sedimentation

$V_t = \frac{g D_p^2 (\rho_p - \rho_f)}{18\mu}$, $\boxed{v_{rad} = v_t \times \frac{\omega^2 r}{g}}$ radial velocity

terminal velocity

terminal velocity

acceleration $a = \omega^2 r$ $v_t = \frac{\pi b (r_2^2 - r_1^2) \times g \times D_p^2 (\rho_p - \rho)}{18\mu \ldots}$

④ The pressure on the wall of the centrifugal (separation of liquid)

$p = \frac{\rho \times \omega^2}{2} (r_2^2 - r_1^2)$.

⑤ efficiency of centrifugal separator.

Separation factor = $\frac{\text{centrifugal force}}{\text{Gravity force}} = \frac{\cancel{m} \omega^2 r}{\cancel{m} g} = \frac{\omega^2 r}{g}$

⑥ Osmotic pressure of solution :-

$\pi = \frac{CRT}{M}$

C = solute concentration kg/m$^3$

T = absolute temp. K.

M = Molecular weight.

Osmotic pressure for ionized solutes.

$\pi = \frac{i CRT}{M}$. NaCl = 2 = i

CaCl$_2$ = 3 = i

separation of liquid in centrifugal

$$\boxed{r_i^2 = \frac{\rho_H r_H^2 - \rho_L r_L^2}{\rho_H - \rho_L}}$$

⑦ Rate of flow through Membrane.

$$\boxed{\frac{dm}{dt} = kA(\Delta P - \underset{(Pa)}{\pi}).}$$

$\Delta \pi$ = net osmotic pressure across the membrane

k = mass transfer coefficient.

$\frac{dm}{dt}$ = the rate of mass transfer (kg/s).

⑧ Flux equation for ultrafiltration

$N_w = A_w (\Delta P - \Delta \pi)$.

$A_w = P_w / L_w$ $N_w$ = water flux rate = kg/s m$^2$

⑨ Membrane Performance

$\dot{m}_w = K_w \times A \times \left(\frac{\Delta P - \Delta \pi}{t}\right)$

$\dot{m}_w$ = rate water flow (kg/s).

$K_w$ = is the coefficient of water permeability through the membrane (kg/m$^2$Pa).

# Heat transfer from fin:-

$$\frac{d^2\theta}{dx^2} - m^2(T_s - T_a) = 0$$

$$m = \sqrt{\frac{h \times P}{K \times A_c}}$$

h = heat transfer
K = thermal conductivity
$T_s$ = surface temp.
$T_a$ = ambient temp.
P = perimeter
$A_c$ = cross sectional area.

# Cylindrical fin section:-

$$\frac{d^2\theta}{dx^2} = \frac{4h}{Kd}(T_s - T_a)$$

# Rectangular fin section:-

$$\frac{d^2\theta}{dx^2} = \frac{2h}{Kt}(T_s - T_a)$$

Kinetic of Microbial growth :- relationship.

ⓐ $t = \frac{1}{k}\log\left(\frac{N_0}{N}\right)$ , $\frac{t}{D} = \log\frac{N_0}{N}$ → sterilizing value

ⓑ $\boxed{D = \frac{2.303}{k}}$

k = growth rate constant
D = decimal reduction time
t = time interval.

Imp ⓒ $\boxed{\frac{D_1}{D_2} = \frac{F_1}{F_2} = \frac{k_2}{k_1} = 10^{\frac{(T_2 - T_1)}{z}} = Q_{10}^{\frac{(T_2-T_1)}{10}} e^{\frac{E_a}{R}\left[\frac{1}{T_2} - \frac{1}{T_1}\right]}}$

$\boxed{\text{Sterilizing value} = \log\frac{N_0}{N}}$

$N_0$ = initial spore load, also know as contamination level.

N = sterility level.

ⓓ To achieve same degree of sterility at two different time and temp condition (pasteurization of milk).

$$\left(\frac{t_1}{D_{121}}\right)10^{\frac{T_1 - 121}{z}} = \left(\frac{t_2}{D_{121}}\right)(10)^{\frac{T_2-121}{z}}$$

$t_1$ = processing time at temp. $T_1$
$t_2$ = processing time at temp $T_2$

$\boxed{D \propto 1/k}$

$\frac{N}{N_0} = 2^n, \Rightarrow N = N_0 2^n$

$n = t/G$ → generation time
↓
no. of generation

ⓔ $Q_{10} = 10^{\frac{E_a}{2.303R}\left(\frac{10}{T(T+10)}\right)}$

Ⓕ Lethal Rate (LR):-

$$LR = 10^{\left(\frac{T-121}{z}\right)}$$

Ⓖ First order reaction

$$\ln\left(\frac{C}{C_0}\right) = -kt$$

Number of generation can also be calculated as

$$N = N_0 2^n$$

$$\log N = \log N_0 + n\log 2$$

Half life:

$$t_{0.5} = \frac{0.693}{K}$$

~~[illegible]~~ thermal death time.

$\boxed{S.V. \times D = F}$

$$\log\frac{D_1}{D_2} = \frac{E_a}{2.303R}\left[\frac{1}{T_1} - \frac{1}{T_2}\right]$$

Ⓗ $\boxed{Z = \frac{2.303RT_m^2}{E_a}}$

ⓘ $t = D\log\frac{N_0}{N}$

ⓙ $kt = \ln N/N_0$

Z = no. of degree (°C or F)

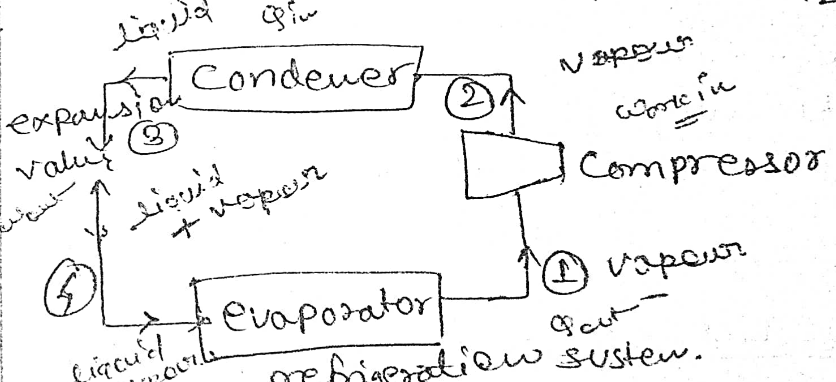
$$Z = \frac{(T_2 - T_1)}{\log(D_1) - \log D_2}$$

Refrigeration and freezing:-

Coefficient of performance (COP)

—×—×—

$$COP = \frac{\text{refrigeration effect}}{\text{work input}} = \frac{h_1 - h_4}{h_2 - h_1}$$



refrigeration system.

1 ton of refrigeration = 3.52 kw = 50 kcal/
= 3000 ka

Coefficient of performance of reverse carnot

$$(COP) = \frac{\text{heat removed}}{\text{work done}} = \frac{T_1}{T_2 - T_1}$$

freezing of foods (plank's equation)

$$t_f = \frac{\rho \lambda}{T_f - T_a}\left[\frac{Pa}{h} + \frac{Ra^2}{k}\right]$$

Calculation of thickness of Ice layer of Ice. cream in scraped surface heat exchanger.

$$A \times U \times \Delta\theta \times t = A \times \delta \times \rho_{ice} \times \lambda_s$$

$$\boxed{\delta = \frac{U \times \Delta\theta \times t}{\rho_{ice} \times \lambda_s}} \quad \boxed{t = \frac{1}{n \times N}}$$

n = no. of blades
N = speed of scrapper

RQ (Respiratory Quotient)

$$= \frac{\text{Volume of carbon dioxide produced}}{\text{Volume of oxygen consumed}}$$

Note

① capacity elevator (t/hr) = $\frac{\text{Capacity } m^3/hr \times \text{density } (kg/m^3)}{1000}$

② Horse power (hp) = $\frac{Q \times L \times W \times F}{4566}$ Screw conveyor

Q (m³/hr), L (m), W (kg/m³)

Q = conveyor capacity m³/h
L = conveyor length m
W = bulk material kg/m³
F = Material factor (paddy, e.g.)

↓

$$HP(Power) = \frac{K \times C \times L}{75}$$

C = capacity kg/s
L = Conveyor length (m)
K = Material factor 0.4

Q.1 Skimming efficiency

$$(SE) = \frac{\text{amount of fat in cream}}{\text{amount of fat in milk.}}$$

Q.2 water activity :- ($a_w$) is defined the ratio of the water vapour pressure of the food to the vapour pressure of pure water at the same temp.

$$a_w = \frac{\text{Vapour pressure of water present in food}}{\text{vapour pressure of pure water at same temp.}}$$

$$= P/P_0$$

$$a_w = \frac{\% \, ERH}{100}$$

range of water activity for any foods lies range 0-1.

Q.3 Raoult's law (water activity).
(ideal Solution)
(water activity equal to mole fraction).

$$a_w = n_w = \frac{\text{mole of water}}{\text{mole of water + moles of solute}} = \frac{w_w/18}{\frac{w_w}{18} + \frac{w_s}{M_s}}$$

$w_s$ = mol weight of water.
$M_s$ = Molecular weight of solute.
$n_w$ = Mole fraction of water.
$w_s$ = weight of solute.

Norrish Equation :-
Calculate the water activity

$$\log \frac{a_w}{x_w} = -k(1-x_w)^2$$

$$a_w = x_w \times 10^{-k(1-x_w)^2}$$

$x_w$ = mole fraction of water
k = Constant depends on solute.

Henderson Equation :-

$$\boxed{1 - RH = e^{-CTM_e^n}}$$

c, n = Constant based on the Material
RH = Relative humidity in decimal.

Heat transfer needed for vaporizing will be

$q = A k_y (H_s - H) \lambda$

$k_y$ = Mass transfer cofficient kg moles/m²s

**Estimations for total Drying time.**

Equation for moisture removal rate for constant rate drying period is.

$$R_c = \frac{dw}{dt} = \frac{w_0 - w_c}{t_c}$$

$w_0$ = initial moisture content (kg water/kg dry solid)

$w_c$ = critical moisture content

time for falling rate drying

$$t_f = \frac{w_c}{R_c} \ln(w_c/w_f)$$

total drying time

$$t = t_c + t_f$$

$$\boxed{t = \frac{w_0 - w_c}{R_c} + \frac{w_c}{R_c} \ln\left(\frac{w_c}{w_f}\right)}$$

$w_f$ - final moisture content

**Drying Rate Constant :-**

thin layer drying equation

$$\frac{M - M_e}{M_0 - M_e} = \bar{e}^{Kt} \text{ or } t = \frac{1}{K} \ln\left(\frac{M - M_e}{M_0 - M_e}\right)$$

$M_0$ = initial moisture content

Moisture ratio (MR)

$$MR = \frac{M - M_e}{M_0 - M_e}$$ K = drying constant

**Coefficient of performance (COP)**

$$COP = \frac{t_3 - t_2}{t_2 - t_1} \text{ °c}$$

$t_3$ = dry temp of exhaust air °c

$t_2$ = dry temp of heated air °c

$t_1$ = dry temp of ambient air °c

**Heat utilization factor :**

$$HUF = \frac{\text{heat utilized}}{\text{heat supplied}}.$$

$$= \frac{\text{drop in dry bulb temp of drying air}}{\text{increase in dry bulb temp of ambient air}}$$

$$= \frac{t_2 - t_3}{t_2 - t_1}$$

⇒ Relationship b/w HUF and COP

HUF = 1 − COP

$$\text{Overall thermal efficiency \%} = \frac{\text{energy used for evaporation}}{\text{heat energy supplied}} \times 100$$

$$\boxed{HUF = 1 - COP}$$

Energy Requirement for Atomization of milk.. :-

Total energy required to atomize the given volume.

$$\Rightarrow \sigma \times \pi D^2 (N^{1/3} - 1) \times n$$

The number of drops of milk n may be calulated by

$$n = \frac{\text{Volume of milk}}{\text{Volume of one drop}} = \frac{V_m}{\frac{\pi}{6} D^3}$$

Energy requirement during atomization :

$$N = \frac{\text{Volume of drop}}{\text{Volume of droplet}} = \frac{\frac{\pi}{6} D^3}{\frac{\pi}{6} \times d^3} = \left(\frac{D}{d}\right)^3$$

**Freeze drying :-**

$$t = \frac{x^2 \rho_f \lambda_s (m_i - m_f)}{8 k_d (T_s - T_i)} \text{ sec}$$

$k_d$ = thermal conductivity W/mK.

$\lambda_s$ = latent heat of sublima

$x$ = slab thickness, m

$\rho_f$ = density of the frozen food kg/m³

$Q_{ad} = k_a(V_L - V_c)$

## # Fluidized Bed Drying:-

The air velocity at which fluidization occure is called minimum fluidization velocity and is calculated for spherical particles.

$$V = \frac{(\rho_s - \rho)\, d^2 \varepsilon^3}{\mu \quad 180(1-\varepsilon)}$$

$\rho$ = density of air

$\mu$ = viscocity of air $Ns/m^2$

## # Rehydration Ratio:-

$$R.R = \frac{w_r}{w_d} = \frac{\text{rehydrated Sample}}{\text{dehydrated Sample}}.$$

## Humid volume of air $v_H$ =

ⓐ $v_H = (0.00283 + 0.00456\,H)T$

T = temperature in kelvin (K)

ⓑ ~~specific humidity~~ specific humidity / absolute humidity $= 0.622 \frac{P_w}{P_a}$

ⓒ humid heat = $(0.24 + 0.45H)$

H = specific humidity

ⓓ Enthaphy :-

$h = (0.24 + 0.45H)T + 597H$

(ɑ)ⁱ (KJ/Kg) Kcal/Kg

## # drying equation:-

$$\boxed{\frac{M - M_e}{M_o - M_e} = e^{-k\theta}}$$

$M_e$ = equlibrium moisture content

$M_o$ = initial Moisture of grain

$M$ = instantaneous Moisture of grain.

$\theta$ = time.

## :- Momentum Transfer :-

## # Newton's law of viscosity

$$\tau = \mu \times \frac{dv}{dy}$$

$\mu = \frac{\text{Shearing stress } (\tau)}{\text{Rate of shearing strain } (dv/dy)}$

Shearing force $\tau = F/A$

Kinematic viscosity $= \nu = \mu/\rho$.

Importance Dimensionless Number in fluid flow:-

ⓐ Euler No. $= \frac{\text{pressure force}}{\text{Inertial force}} = \frac{\Delta P}{\rho V^2}$

ⓑ Froude No. $= \frac{\text{Inertial force}}{\text{gravity force}} = \frac{V}{\sqrt{gD}}$ $\left(\frac{N^2 D}{g}\right)$

ⓒ Mach No. $= \frac{\text{Local velocity}}{\text{Sonic velocity}} = \frac{V}{C}$

ⓓ weber No. $= \frac{\text{Inertial force}}{\text{Surface tension force}} = \frac{\rho V^2 L}{\sigma}$

C = Speed of sound in fluid

$\sigma$ = surface tension of the fluid.

# Equivalent Diameter:-

Hydraulic mean dia $D_H$ = $\frac{4\times \text{cross sectional area}}{\text{wetted perimeter}}$

$= \frac{4A}{P_w} = 4\times R_H$

$R_H$ = Hydraulic radius

$D_H = \frac{\frac{4\times\pi D^2}{4}}{\pi D} = D$ → tube of diameter

# Continuity equation:-

$a_1V_1 = a_2V_2 = Q$ ⇒ volumetric flow rate ($m^3/s$)

## Power requirements for pumping:

$\boxed{P_B = \dot{m}\times W_p} = \dot{m}\times\frac{\Delta y}{\eta}$, J/s, or W

$W_p$ = pump work, J/kg.

Power rating = $\dot{m}\times E_p$ (J/s, W),

$\dot{m}$ = mass flow rate kg/s,

$E_p$ = Energy supplied by pump J/kg.

pump Affinity Law:-

① $Q\propto N$ ② $H\propto N^2$ ③ $P\propto N^3$

discharge Head Power

N = Speed of revolution (N).

Speed constant and varying dia.

ⓐ $Q\propto D^3$. ⓑ $H\propto D^2$ ⓒ $P\propto D^5$

D = impeller diameter

Combining pump laws.

$\frac{Q_1}{Q_2} = \frac{N_1D_1^3}{N_2D_2^3}$, $\frac{H_1}{H_2} = \frac{N_1^2D_1^2}{N_2^2D_2^2}$, $\frac{P_1}{P_2} = \frac{N_1^3D_1^5}{N_2^3D_2^5}$

# Laminar flow in a cylindrical pipe or Tube.

ⓐ Maximum velocity $\boxed{V_{max} = \frac{\Delta P\times R^2}{4\times\mu\times L}}$

Volumetric flow rate

$Q = A\times\bar{V}$

$= \pi R^2\bar{V} = \frac{\pi\Delta R\times D^4}{128\,\mu\times L} = \frac{\pi\Delta P\times R^4}{8\mu L}$

this equation is called $\boxed{V = \frac{\Delta P\times D^2}{32\mu L}}$

Hagen-poiseuille Equa

Used:- the viscosity of a Newtonian flui

from pressure drop.

# Pressure drop and friction loss in Laminar flow.

$\frac{ava}{\bar{V}} =$

$\Delta P_f = P_1 - P_2 = \frac{4fL\rho\times\bar{V}^2}{2D}$

This equation for head loss due to fri in a pipe is expressed

$h_f = \frac{4fLV^2}{2gd} = \frac{V_{max}}{2} =$

f = fanning factor

laminar flow in a pipe.

$f = \frac{16}{Re} = \frac{16\times\mu}{\rho VD}$

→ Pitot tube

ⓐ velocity $V = C_p\sqrt{\frac{2\Delta P}{\rho}} = C_p\sqrt{2gh}$

$C_p$ = Cofficient of pitot tube

$h$ = rise of fluid in tube.

ⓑ **Fan power requirements :-**

$$P_f = \frac{Q \cdot P_t}{\eta_f \, \eta_m}$$

$Q$ = air flow rate m³/s

$P_f$ = fan power input

$P_t$ = fan total pressure Pa.

# Compressor work input for Isothermal compression :-

$$W = \frac{RT_1}{M} \ln \frac{P_2}{P_1}$$

# fluid flow through porous media :-

(Void fraction or Porosity in a Packed bed)

$$\varepsilon = \frac{\text{Volume of voids in bed}}{\text{total volume of bed (solid + void)}}$$

$$= \frac{V_v}{V_T} = \frac{V_v}{(V_v + V_s)}$$

The void volume and volume of particles may also be written

⇒ $\boxed{\text{Void volume} = \frac{\varepsilon}{1-\varepsilon} \times \text{Volume of particles}}$

Relationship b/w bed height and porosity

$$\boxed{\frac{L_1}{L_2} = \frac{1-\varepsilon_2}{1-\varepsilon_1}}$$

$L_1$ = is the height of bed

$\varepsilon_1$ = Porosity.

Mass of drying Material in bed

$$m = \frac{\pi}{4} d^2 h \rho (1-\varepsilon)$$

# Pressure drop at Minimum fluidization

Pressure drop at minimum fluidization

$$\Delta P_{mf} = L_{mf}(1-\varepsilon_{mf})(\rho_p - \rho) g.$$

$L_{mf}$ = minimum height of fluidized bed

$\rho$ = fluid density.

$\rho_p$ = Particles density.

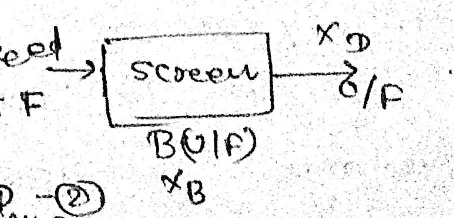
fluidization :- $\boxed{L_{mf} = \frac{L}{1-\varepsilon_{mf}}}$

$L$ = Compact height

Separation effectiveness of paddy separator

overall Material balance.

On paddy rice



$F = B + D$ —①

$F x_{f} = B x_B + D x_D$ —②

equation ②

$F x_f = (F - D) x_B + D x_D$

$F x_f = F x_B - D x_B + D x_D$

$(x_B - x_D) D = (x_B - x_f) F$

uidification

P)g

dized bed

parator

D

/F

$$\frac{}{F} = \frac{(x_B - x_f)}{x_B - x_D} \quad - ③$$

Now equation ②

$$Fx_f = Bx_B + (F-B)x_D$$

$$Fx_f = Bx_B + Fx_D - Bx_D$$

$$F(x_f - x_D) = B(x_B - x_D)$$

$$\left(\frac{x_f - x_D}{x_B - x_D}\right) = \frac{B}{F} \quad - ④$$

Overall efficiency $\eta_{overall} = \eta_A \times \eta_B$

$$= \frac{Bx_B}{Fx_f} \times \frac{D(1-x_D)}{F(1-x_f)}$$

year

$$= \frac{(x_f - x_D)x_B}{(x_B - x_D)x_f} \times \frac{(x_B - x_f)}{(x_B - x_D)} \times \frac{(1-x_D)}{(1-x_f)}$$

$$\boxed{\eta_{overall} = \frac{(x_f - x_D)(x_B - x_f)(1-x_D)x_B}{(x_B - x_D)^2 x_f (1-x_f)}}$$

Efficien

## Psychrometrics:-

① $SA = 0.622 \times \frac{P_w}{P_a} = \frac{0.622 \times P_w}{P - P_w}$

absolute humidity

relationship :- temp and Humidity

$$\boxed{T_3 = \frac{T_1 H_2 - T_2 H_1 + H_3(T_2 - T_1)}{H_2 - H_1}}$$

② enthaply = $(0.24 + 0.45H)T + 597H$ kcal/kg

$T = °c$

③ Humid volume = $(0.00283 + 0.00456 \times H) \times T$

$T =$ is $K$

(m³/kg)

humid heat $_s$ = $(0.24 + 0.45H)$.

partial pressure = (Carrier equation)

$$(\text{kPa})\ P_w = P_s - \frac{(P - P_s)(T_d - T_w)}{1800 - 1.44 T_w}$$

T = dry bulb temp °c

$T_w$ = wet bulb temp.

→ wet Bulb temperature.

$$\frac{H - H_w}{T - T_w} = \frac{h/M_a k_y}{\lambda_w} = \frac{-C_s}{\lambda_w} = \frac{-950}{\lambda_w}$$

$M_a$ = Molecular weight

$k_y$ = Mass transfer

T = dry bulb temp

$T_w$ = wet bulb temp

h = heat transfer coeff

$\lambda_w$ = latent heat

$= C_s = 950\ J/kg\ K$

psychrometric ratio $C_s = \frac{h}{M_a k_y}$.

IMP

Rate of drying $\boxed{R = \frac{h(T_{db} - T_w)}{\lambda_w}}$

Uniformity index:- measure of relati uniformity.

① Volume surface mean dia. / Sauter mean dia $D_s = \frac{1}{\sum_{i=1}^{n} \frac{x_i}{D_{pi}}}$

① Mass mean dia. $\vec{D}_w = \sum_{i=1}^{n} x_i D_{pi}$

③ Volume mean dia. $\vec{D}_v = \left[\frac{1}{\sum_{i=1}^{n} \frac{x_i}{D^3_{pi}}}\right]^{1/3}$

factor for Radiation f.

$F_{12} = \frac{1}{\frac{1}{\epsilon_1}+\frac{1}{\epsilon_2}-1}$  $\epsilon_1$ = emissivity of plane 1, $\epsilon_2$ = emissivity of plane 2

View factor between two surfaces = $\frac{\cos\theta_1 \cos\theta_2 \, dA_1 dA_2}{\pi r^2}$

② Effectiveness of double pipe heat exchanger for counter flow

$$\varepsilon = \frac{1-e^{[-NTU(1-C_r)]}}{1-C_r e^{[-NTU(1-C_r)]}}$$

$C_r = 1$  $\varepsilon = \frac{NTU}{1+NTU}$ or $\boxed{NTU = \frac{\varepsilon}{1-\varepsilon}}$

Radiation (HTB) - two infinite grey cylinder

$q = \frac{\sigma A_1(T_1^4 - T_2^4)}{\frac{1}{\epsilon_1}+\frac{A_1}{A_2}\left(\frac{1}{\epsilon_2}-1\right)}$  A = πdL

Sphere

$q = \frac{\sigma A_1(T_1^4 - T_2^4)}{\frac{1}{\epsilon_1}+\frac{A_1}{A_2}\left(\frac{1}{\epsilon_2}-1\right)}$  A = 4πr²

③ parallel flow heat exchanger effectiveness double pipe

Capacity ratio $C_r = \frac{C_{min}}{C_{max}}$

$$\varepsilon = \frac{1-e^{[-NTU(1+C_r)]}}{1+C_r} \qquad NTU = \frac{-\ln[1-\varepsilon(1+C_r)]}{1+C_r}$$

③ Ball mill works on the principle of

ⓐ Impact

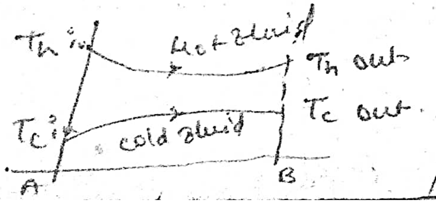
LMTD :- (Logarithmic average) of the temp. difference b/w the hot and cold streams at each end of the exchanger.

② The larger the LMTD more heat is transfered.

③ The LMTD is valid only for heat exchanger with one shell pass and one tube pass.

④ only flow is co-current and counter current.

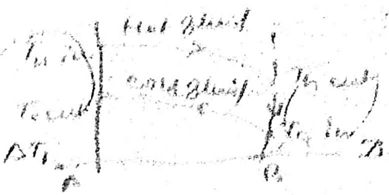
Parallel flow exchanger :-



$LMTD = \frac{(T_{hi} \text{ [illegible]}) - (T_{ho} - T_{co})}{\ln \text{ [illegible] } T_{ci}}$

Counter flow exchanger.

$LMTD = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln \frac{(T_{hi} - T_{co})}{(T_{ho} - T_{ci})}}$



LMTD area of pipe :-

$A_{lm} = \frac{2\pi L(r_o - r_i)}{\ln(r_o/r_i)}$.

LMTD correct formula :-

$Q = A \times U \times \overline{\Delta T} \times f$ ~ correction factor

$\overline{\Delta T}$ : LMTD

Calorific value of rice husk = 3000 kcal/kg

critical radius of for cylindrical system $r_c = \frac{k}{h_o}$

critical radius for spherical system $r_c = \frac{2k}{h_o}$

⇒ Note only for constant rate drying Moisture removal rate per unit area.

$$\boxed{\frac{w_o - w_c}{t_c} = \frac{m_w}{A} = \frac{h(T-T_w)}{\lambda_w}}$$

T = dry bulb temp,
Tw = wet bulb temp
mw = water remove rate.

$t_c = \frac{\lambda_w(w_o - w_c)}{hA(T_o - T_w)}$

this equation time is 0 unit

Now ~~Mw~~ $\boxed{\frac{M_w}{A} = \frac{ht(T-T_w)}{\lambda_w}}$ → time taken =

$R_c = \frac{W}{A t_c}(x_1 - x_2)$, db and

$\boxed{W}$ = mass of dry solid

Falling film evaporator.

Mass flow rate

$$\boxed{\dot m_v = \frac{\pi d L U \times \Delta T}{\lambda}}$$

Critical thickness of insulation for spherical system

$r_c - r_1$

$\frac{2k}{h} - d$

① $Mc(wb) = \frac{Mc(db)}{1+Mc(db)}$

② $Mc(db) = \frac{Mc(wb)}{1-Mc(wb)}$

$Mc(wb) = \frac{W_w}{W} \times 100$

W = total weight

$Mc(db) = \frac{W_w}{W_d} \times 100$