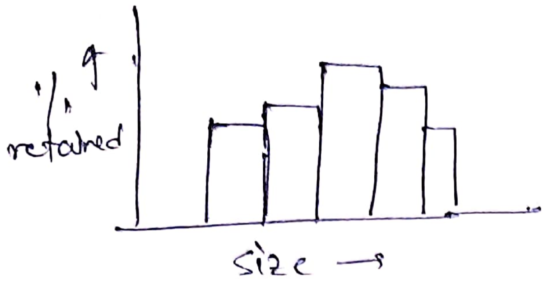
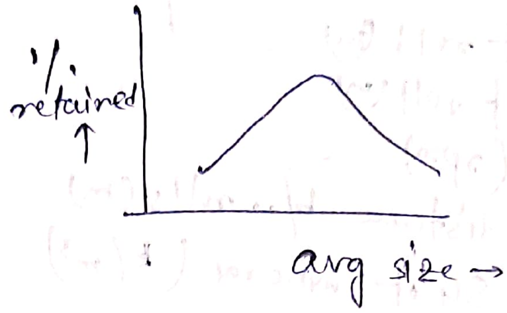
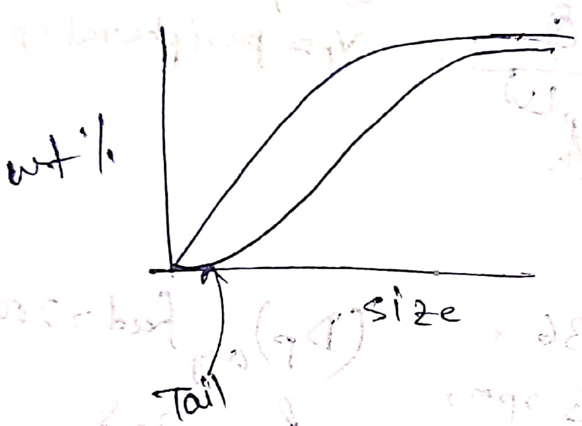
09/10

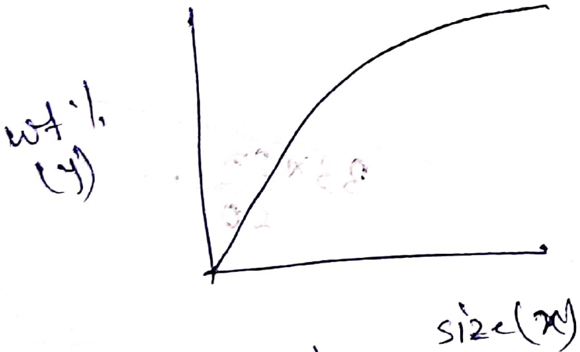
Differential :-

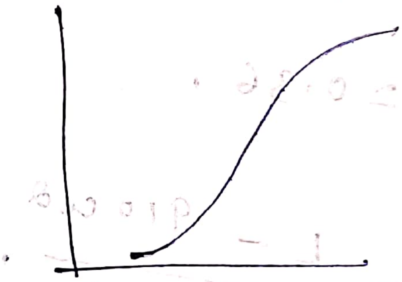




Cumulative :-







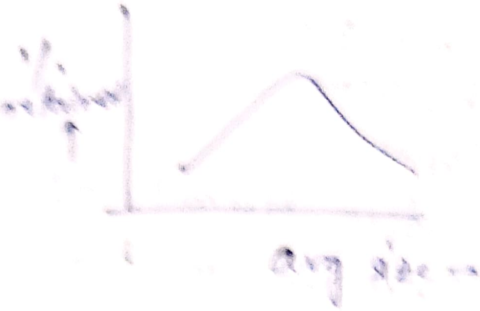
In log log graph, linear graph.

log-log graph, $\boxed{y = b e^{(x/a)}}$

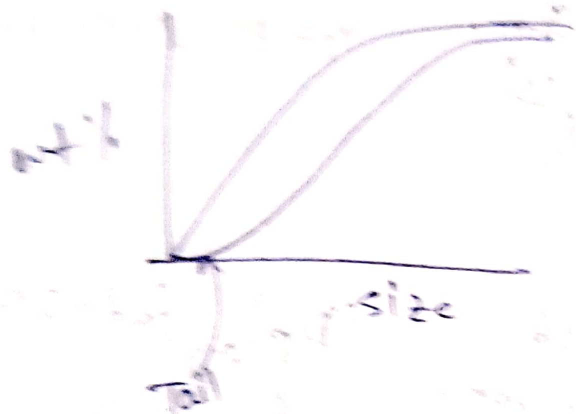
Rosin-Rammler distribution

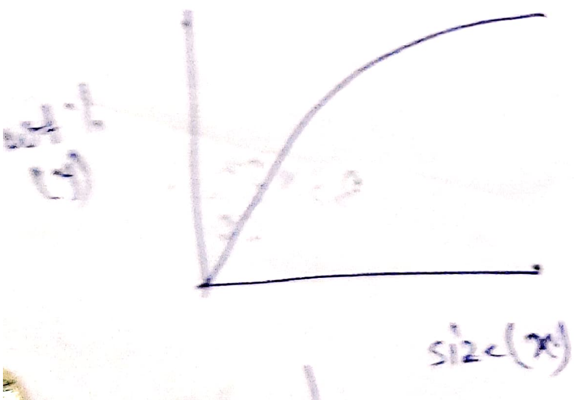
07/10

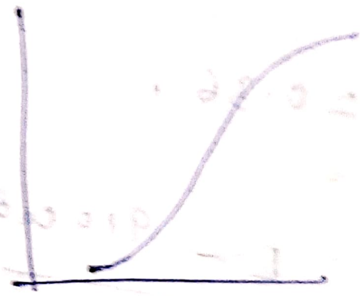
Differential :-



Cumulative :-



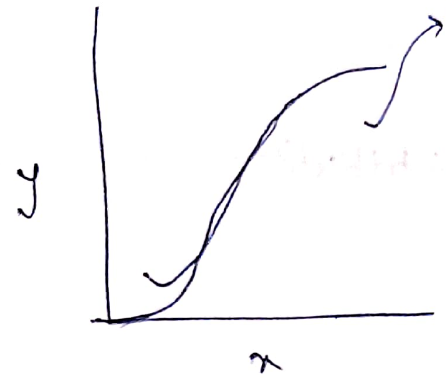




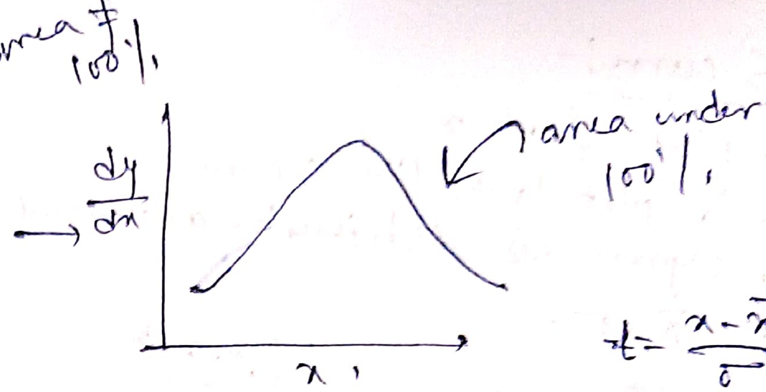
in log log graph, linear graph.

log-log graph, $\boxed{y = b e^{(x/a)}}$

Rosin - Rammler distribution



$\longrightarrow \frac{dy}{dx}$



$$t = \frac{x - \bar{x}}{\sigma\,(SD)}.$$

$$\frac{dy}{dx} = \frac{1}{\sigma\sqrt{2\pi}} \cdot \exp\left\{\left[-\frac{1}{2}\left(\frac{x-\bar{x}}{\sigma}\right)^2\right]\right\}$$

perfect normal distribution from. $-4\sigma \le t \le 4\sigma$

$\frac{dy}{dx}$ v/s t

(avg) x	y (wt)
2	
4	
6	
8	
10	

wt avg $\bar{x} = \frac{\sum xy}{\sum y}$.

$$\frac{dy}{dx} = \frac{1}{\sigma\sqrt{2\pi}} \exp(\quad)$$

① avg size (x)

Rosin Ramler distribution $\boxed{\phi = 100\, e^{(-bx^n)}}$

ϕ → wt % (ϕ).

$$\log\left(-\log\left(\frac{\phi}{100}\right)\right) = \log b + n \log x.$$

R^2 = root mean square error.

$R^2 \to 1$ (best fit)

$R^2 \to 0$ (bad fit).

(for S curve, Rosin Ramler distribution is not used)

Scanned with OKEN Scanner

S curve:-

1. Plot ϕ v/s x.
2. if plot looks like S-curve
3. express size distribution as normal distribution.
4. $\bar{x}, \sigma$.

$$\frac{d\phi}{dx} = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\bar{x}}{\sigma}\right)^2}$$

5. If plot looks like exp curve.
6. Go to Rosin-Rammler distribution.
7. Estimate b and n.
8. To " these plot b/w $\log(-\log(\phi/100))$ v/s $\log x$.

$\Downarrow$ from slope and intercept → b and n values.

Fine particle characterisation:-

particle size < 10 micron.

Now, " " < 2.5 micron.

Microscopic techniques:-

optical :- theoretically, 0.18 to 0150 microns.

actual 3 to 150 microns.

Limit of resolution $d = \frac{f\lambda}{NA}$.

f = factor = 0.6

λ = WL

NA = numerical aperture = $\mu \sin\phi$.

μ = refractive index

Laser diffraction! -

size < 3 micron,

Ray leigh scattering,

$$I = I_0 \left(\frac{1 + \cos^2\theta}{2R^2} \right) \left(\frac{2\pi}{\lambda} \right)^4 \left(\frac{m^2 - 1}{n^2 + 2} \right)^2 \left(\frac{d}{2} \right)^6 .$$

Mie Scattering,

$$I = E \left\{ k^2 D^4 [JI]^2 \theta + (k_1\theta)^1 + (k_3\theta)^3 + (k_5\theta)^5 + \frac{k^4 d^6 (m-1)^2 \theta^4}{8\pi} \right\}.$$

Dynamic Light Scattering (DLS).

Γ = diffusion length,

$\Gamma = D_T q^2$. D_T = diffusion coeff

$$q = \frac{4\pi n}{\lambda} \sin\frac{\theta}{2} .$$

Colloid mill:-
mainly for wet feeds.

Fluid energy mill
dry feed

$(x - \bar{x}^2)$
$(x - \bar{x})$

16/10

(1)

Size (microns) (x)	Cumulative wt % (y)	Δy	$x \cdot \Delta y$
10	0	0	0
13	3.5	0	0.455
15	10	6.5	0.975
17	25	15	2.55
20	50	25	5
23	75	25	5.75
27	92	17	4.59
30	98	6	1.8
35	100	2	0.7

$$\boxed{\bar{x} = \sum x \left(\frac{\Delta y}{100}\right)}$$

$$\bar{x} = 21.82$$

$$\frac{dy}{dx} = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{x-\bar{x}}{\sigma}\right)^2\right).$$

$$\sigma = \sqrt{\frac{\sum (x-\bar{x})^2 \cdot \Delta y}{\sum \Delta y}}$$

(2) Express the suitable size distribution expression for the given d.

size (microns) x	wt % (Δy)	y (cumulative)	$x\,\Delta y$
2	10.4	10.4	
5	16	26.4	
7	16.1	42.5	
10	7.5	50	
15	6.7	56.7	
20	18.6	75.3	
25	6.1	81.4	
30	7.9	89.3	
35	10.3	99.6	
40	0.4	100	

plot y v/s x — exp curve.

R–R distribution.

$$y = 100 \exp(-bx^n)$$

$$\ln y = \ln 100 - bx^n$$

$$\ln\left(-\ln \frac{y}{100}\right) = \ln b + n \ln x$$

$$Y = mX + c$$

plot $\ln\left(-\ln \frac{y}{100}\right)$ v/s $\ln x$.

after plotting $y = -1.5867x + 2.7857$

$R^2 = 0.6366$

$m = -1.158$

$\ln b = 2.7857$ $\Rightarrow b = 16.2$

Dynamic Light Scattering (DLS) :-

Fine particles
↓
Brownian motion.

(Translational) Diffusion Coeff (D_T) — depends on particle size.

Flux ∝ concⁿ gradient

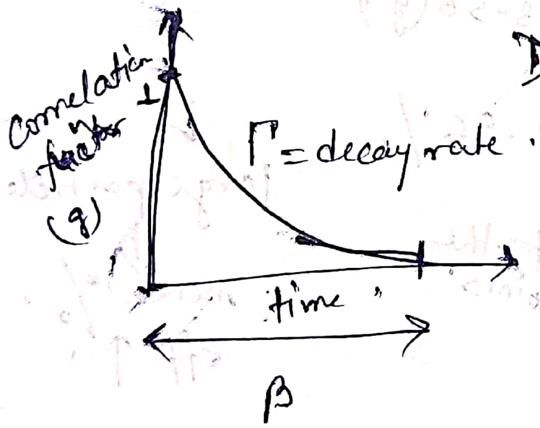
$$\text{Flux} = D_T \cdot \frac{dc}{dx}$$

Stoke - Equⁿ :-

$$\boxed{R_p = \frac{KT}{6\pi \mu D_T}}$$

K = Boltzman const.

Intensity v/s time graph → Correlation funcⁿ.



Delay time.

$$\boxed{g = 1 + \beta e^{-\Gamma t}}$$

$$\boxed{\Gamma = \frac{D_T}{q^2}}$$

q = scattering factor

$$= \frac{4\pi n_o}{\lambda} \sin\left(\frac{\theta}{2}\right)$$

n_o = ref index.
λ = WL of incident lt.
θ = incident angle.

Reverse flow cyclone seperator :-

wake formation or boundary layer } → frictional losses are high → ΔP high

cyclone ← particles from gas
hydroclone ← " " liquid.

30/10

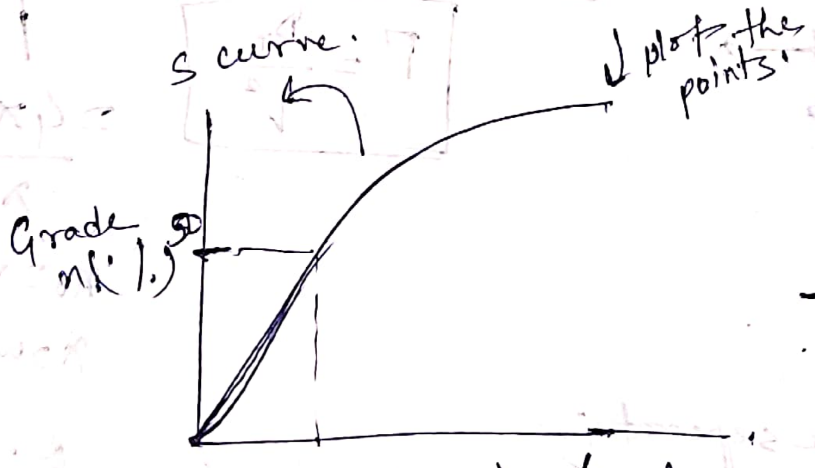
(1) A cyclone seperator is used to seperate coal porticles from air. Estimate the cut particle diameter of the seperator. Below table, gives information of the size distribution of the feed and collected sample.

avg size	size (microns)	wt of sample: feed	wt of sample: collected particle	Grade η
2.5	0-5	10	0.1	$0.1/10 \times 100 = 1\%$
7.5	5-10	15	3.53	$3.53/15 \times 100 = 23$[illegible]
12.5	10-15	25	18	$18/25 \times 100 = 7$[illegible]
17.5	15-20	30	27.3	$27.3/30 \times 100 =$ [illegible]
22.5	20-25	15	14.63	$14.63/15 \times 100 =$ [illegible]
27.5	25-30	5	5	$5/5 \times 100 = 100$

total cut (mass) = 100 g   68.56 (g)

$$\text{overall } (\eta) = \frac{68.56}{100} \times 100 = 68.56\%$$

large particle
⇓
more % eff ↑



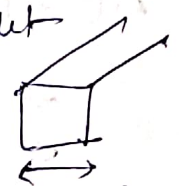
→ start with origin.

cut particle diameter = d_{50}.

∴ Here $d_{50} = 9\,\mu m$.

(2) Inlet width = B_c = 15 cm.
shortest length of 25 cm with the diameter 0.5 m operates at five effective turns. Gas temp^r = 345 K and inlet vel = 20 m/s.
avg particle size = 10 μm.
particle density = 1.2 g/cc.
density of air = 1.2 kg/m^3.
viscosity " μ = 0.0745 kg/m.h.

inlet



15 cm.

$$\rightarrow d_{pc} = \left(\frac{9 \mu B_c}{2 \pi N V_i (\rho_p - \rho)} \right)^{1/2}.$$

$\frac{1.2 \times 10^{-3}}{10^{-6}}$

1.2×10^{-3}.

$$= \frac{9 \times 0.0745 \times 0.15}{3600 \times 2 \times \pi \times 5 \times 20 \times 1.2 \times (1000 - 1)}$$

$$d_{pc} = \underline{6.09 \times 10^{-6} \text{ m}}.$$

$$\text{pressure drop} = \Delta P = 0.8 \frac{\rho_g V_i^2 ab}{D_o^2}$$

ab = inlet area.

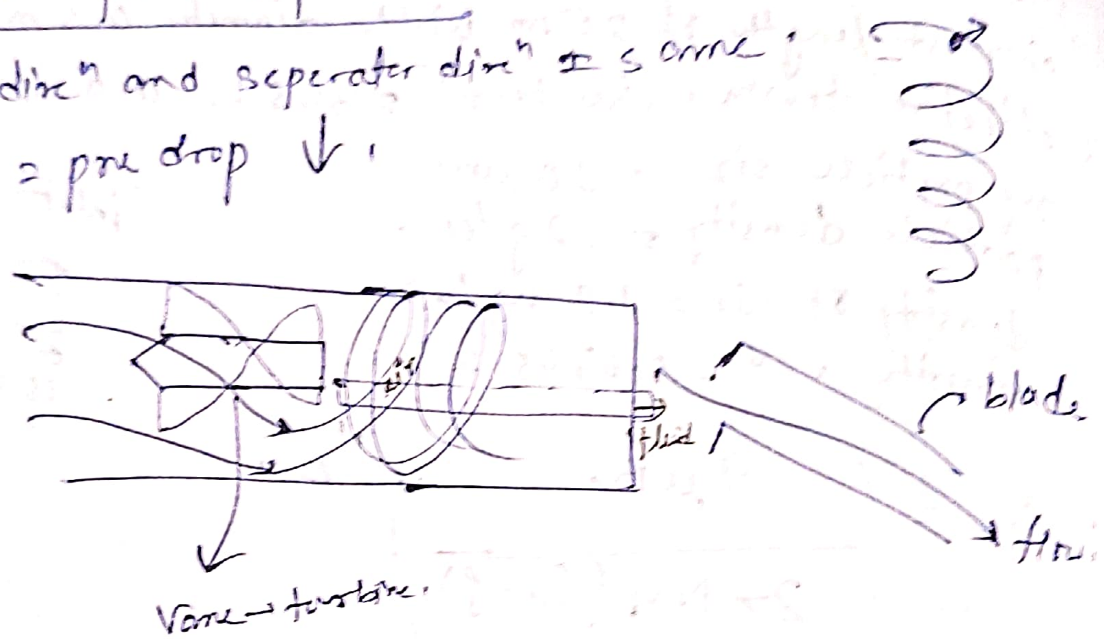
$$= 0.8 \times \frac{1.2 \times 20 \times 20 \times (0.15)^2}{(0.5)^2}.$$

$$\Delta P = 34.56 \text{ Pa}$$

Axial flow cyclone seperator;-

Flow dirⁿ and seperator dirⁿ is same.

ΔP = pre drop $\downarrow$.



Electrostatic Precipitator:-

Used for fine gas.

Charged particles → Wet Esp.

Necessary Conditions:-

voltage:-

$$V = 18\left[1 + \frac{0.3}{R_1^{0.5}}\right] R_1 \ln\left(\frac{R_2^2}{R_1}\right) \text{ kV.}$$

R_1 = radius of wire electrode

R_2 = " " collecting "

• vel :-

electrical conducting particles.

$$w = 0.16\left[\frac{d_p^2 V^2}{\mu}\right].$$

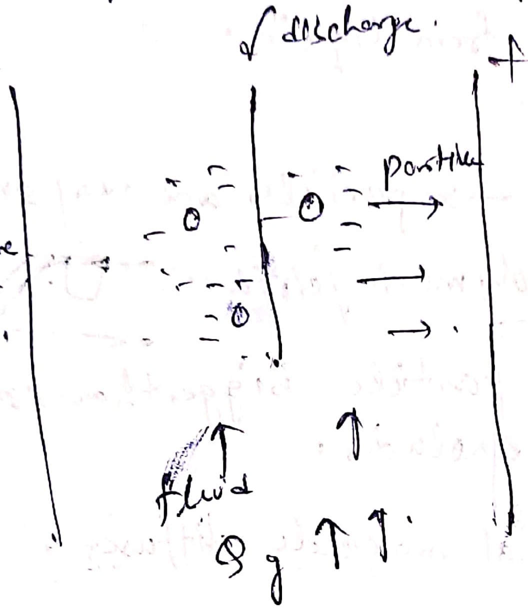
non conducting:-

$$w = 0.095\left[\frac{d_p^2 V^2}{\mu}\right].$$

Collection efficiency, := $1 - \exp\left(Q_g / w.A_e \right)$..

collecting electrode

residence time $= \frac{m^3}{m^3/s} = s$.



particle residence time ≤ gas residence time.
→ for seperation.

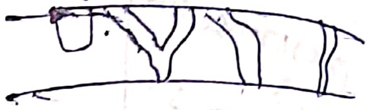
conducting particles —— ~~pros~~ →) conductivity
) charge difference.

Filtration :-

Seperation of solid from liquid.
crystallization.

membrane filtration ⟶ particles are very small.

filter media ⟷ polymeric/cloth.

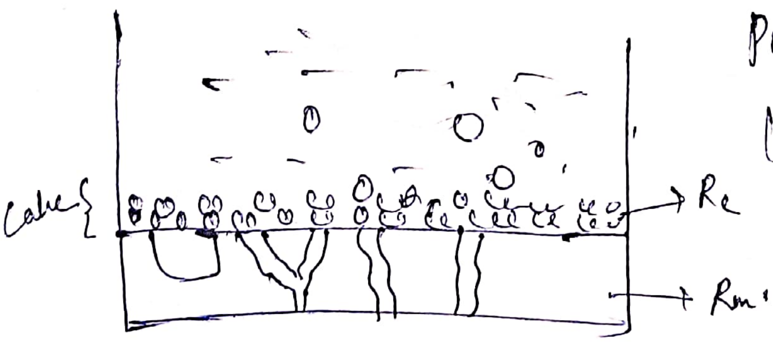


size exclusion — particle bigger than pore size, it excludes.

Diffusion – individual molecule diffuses.
(mass transfer).
↓
int energy — thermal energy migrates the polymer chain.

By applying high pressure — speed ↑

filter media :-



Pores offer resistance.

layer deposited on pores ⟶ cakes.

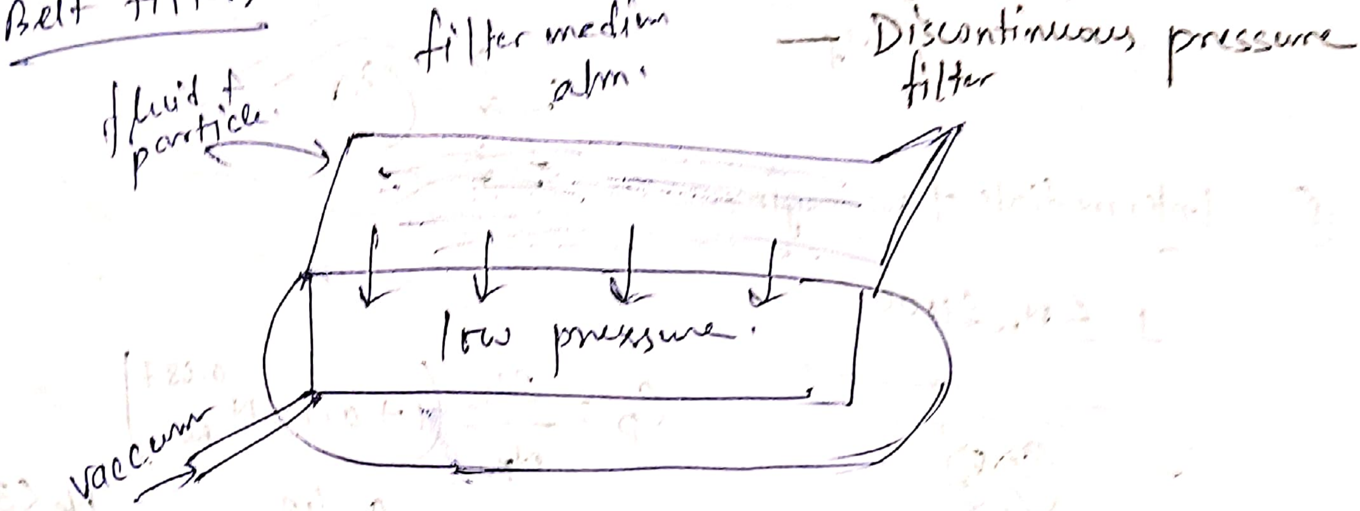
•) Constant pressure ⟶ flowrate with time decreases.

•) constant rate filtration = ΔP ↑ to a maintain flowrate constant.

i) Plate and frame filter press —— external press
i) Rotary drum filter } vaccum
i) Belt filter

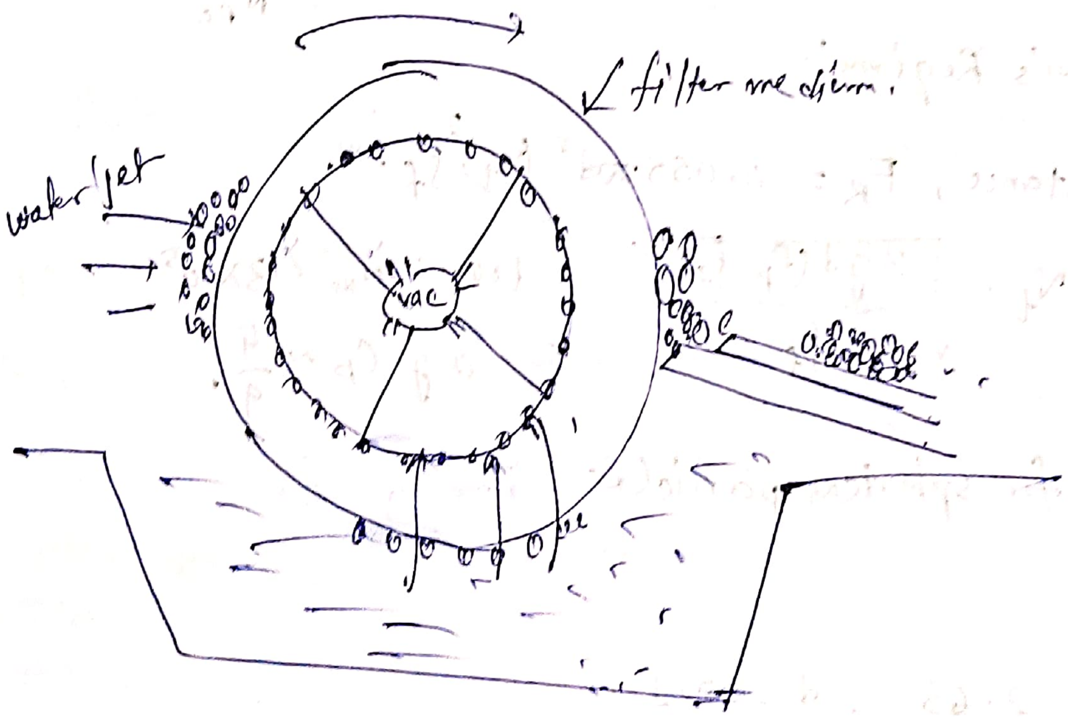
Belt filter:-

— Discontinuous pressure filter



Rotary drum filter:-

→ Continuous vaccum filter

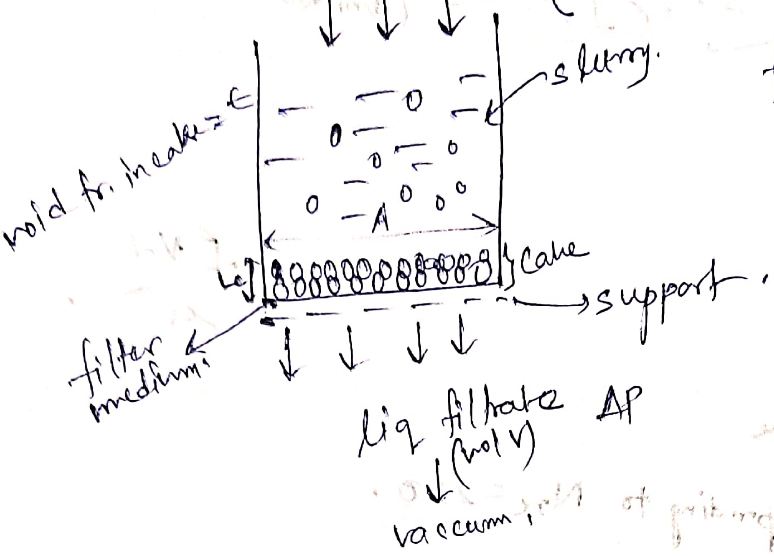


06/11

Cake filtration $\longrightarrow$ concentrated slurry,

feed (solid conc^n = $c_f = \frac{\text{mass}}{\text{vol of slurry}}$)

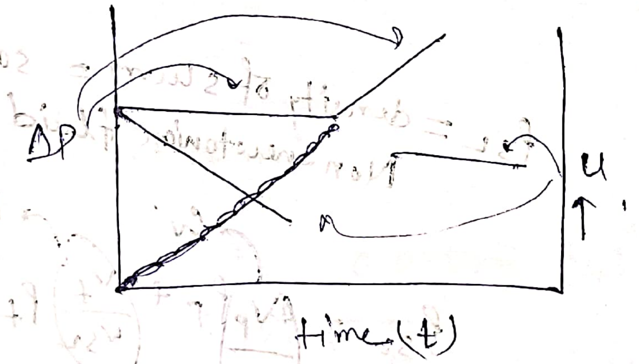
feed flow rate $= q$



$$\frac{\Delta P}{L} = \frac{150 \mu u}{d_p^2} \frac{(1-\epsilon)^2}{\epsilon^3}$$

Flow through cake resembles flow through packed

usually 'Re' in filtration is low.



$\Delta P, L, u = f(t).$

$$d_p = \frac{6}{(S_p/V_p)} \qquad \therefore \frac{S_p}{V_p} = \frac{6}{d}$$

$$\therefore \frac{\Delta P}{L} = \frac{150 \mu u}{36/(S_p/V_p)^2} \frac{(1-\epsilon)^2}{\epsilon^3}$$

$$\frac{\Delta P}{L} = \frac{150}{36}\,\mu u\,\frac{(1-\epsilon)^2}{\epsilon^3}\left(\frac{S_P}{V_P}\right)^2 \quad \text{—— mom balance equ}^n.$$

$$\frac{\Delta P}{L} = k.\,\mu u\,\frac{(1-\epsilon)^2}{\epsilon^3}\cdot\left(\frac{S_P}{V_P}\right)^2 \quad \text{——— (1)}$$

vol of cake $= A L_c$

liq vol in cake $= A L_c \epsilon$

sol " " " $= A L_c (1-\epsilon)$

solids in feed slurry = solids deposit on the filter medium.

$$C_f[q \times t] = A L_c (1-\epsilon)\rho_s$$

if, $C_f \rightarrow \dfrac{\text{mass of solids}}{\text{vol of liq}}$ $\quad$ vol of liq at t in feed.

$$\boxed{C_f \times V_f = A L_c (1-\epsilon)\rho_s}$$

L_c = length of cake at 't'

solid mass balance

liq vol balance

liq in feed slurry = liq in the cake + filtrate.

$$V_f = A L_c \epsilon + V$$

$$u = \frac{\frac{dV(t)}{dt}}{A}$$

$$\therefore C_f (A L_c \epsilon + V) = A L_c (1-\epsilon)\rho_s$$

$$\Rightarrow L_c = \frac{V C_f}{(A(1-\epsilon)\rho_s - A\epsilon C_f)} = \frac{V C_f}{A((1-\epsilon)\rho_s - \epsilon C_f)}$$

if, $C_f \Rightarrow \dfrac{\text{mass of solid}}{\text{vol of \cancel{liq} slurry}}$

$$\frac{C_f}{\rho_s} = \frac{\text{vol of solid}}{\text{vol of slurry}}, \qquad \frac{\rho_s}{C_f} = \frac{V_f + V_s}{V_s}$$

$$\Rightarrow \left(\frac{\rho_s}{C_f} - 1\right) = \frac{V_f}{V_s}, \quad \Rightarrow \frac{V_s}{V_f} = \frac{C_f}{(\rho_s - C_f)}$$

$$\Rightarrow \rho_s \times \frac{V_s}{V_f} = \frac{C_f}{\rho_s - \rho_f} \times \rho_s$$

$$L_c = \frac{V C_f}{A(1-\epsilon)\rho_s - C_f A \epsilon}.$$

$$L_c = \frac{V C_f}{A\left[(1-\epsilon)\rho_s - C_f \epsilon\right]}.$$

$$L_c = \frac{V \vartheta}{A},$$

$(\vartheta \rightarrow \text{symbol}) = \frac{\text{vol of}}{\text{vol of filt}}$

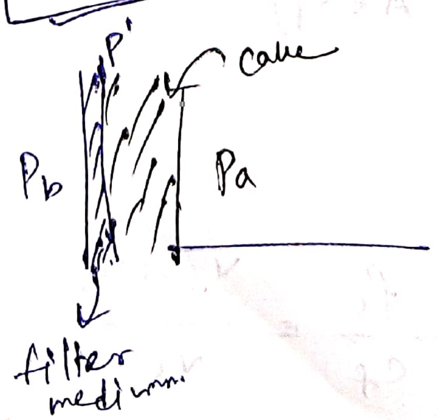
$= \text{Const}.$

$$\frac{\Delta P}{L_c} = k \mu_f u_f \frac{(1-\epsilon)^2}{\epsilon^3} \left(\frac{S_p}{V_p}\right)^2.$$

$$\Delta P = \underbrace{\left[k \frac{(1-\epsilon)^2}{\epsilon^3} \left(\frac{S_p}{V_p}\right)^2\right]}_{\alpha} \cdot u \mu_f \frac{V \vartheta}{A}.$$

$$= \frac{\alpha \vartheta \mu_f V}{A^2} \left(\frac{dV}{dt}\right).$$

$$\boxed{\frac{dt}{dV} = \frac{\alpha \vartheta \mu_f}{A^2} \times \frac{V}{\Delta P_c}}$$



$$\Delta P = P_a - P_B.$$

$$= P_a - p' + p' - P_B.$$

$$\Delta P = \Delta P_c + \Delta P_{fm}$$

R_m = resistance of filter medium.

$$\Delta P \frac{dt}{dV} = \frac{R_m \mu_f}{A} \cdot \frac{1}{\Delta P_f} \longrightarrow \text{negligible}$$

void fraction of cake <<< void fraction of filter medium.

$$\Delta P_c = \frac{\alpha w \mu_f V}{A^2} \cdot \frac{dV}{dt}$$

$$\Delta P_m = \frac{R_m}{A} \mu_f \cdot \frac{dV}{dt}$$

$$\therefore \Delta P = \Delta P_c + \Delta P_m$$

$$\boxed{\Delta P = (\alpha w V + A R_m) \cdot \frac{\mu_f}{A^2} \cdot \frac{dV}{dt}}$$

α = cake resistance.
R_m = filter medium resistance.

$$\int_0^t \Delta P \cdot dt = \int_0^V \frac{\mu_f}{A^2} (\alpha w V + R_m A)\, dV$$

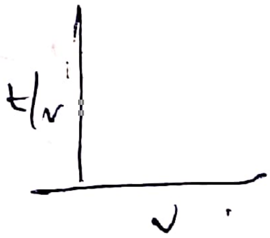
$$\cancel{\Delta P t = \frac{\mu_f}{A^2}(\alpha w + R_m) \frac{V^2}{2}}$$

$$\therefore \Delta P t = \left[\frac{\alpha w \mu_f V^2}{2A^2} + \frac{R_m V \mu_f}{A} \right]$$

constant pressure filtration

$$\therefore \frac{t}{V} = \frac{\alpha w \mu_f}{2A^2 \Delta P} V + \frac{R_m \mu_f}{A \Delta P}$$

m c



$$\frac{\Delta P}{L} = \frac{150\,\mu v (1-\epsilon)^2}{\left(\frac{6}{S_p/v_p}\right)^2 \epsilon^3}$$

filter medim

$$\frac{\Delta P_m}{L_m} = \frac{150}{\left(\frac{6}{S_p/v_p}\right)^2} \cdot \frac{(1-\epsilon)^2}{\epsilon^3} \mu_f v.$$

$$\Delta P_m = \underbrace{\frac{150\, L_m}{\left(\frac{6}{S_p/v_p}\right)^2} \frac{(1-\epsilon)^m}{\epsilon^3}}_{R_m} \mu_f \cdot \frac{\frac{dv}{dt}}{A}.$$

constant rate filtration

$$\frac{dv}{dt} = \frac{v}{t}.$$

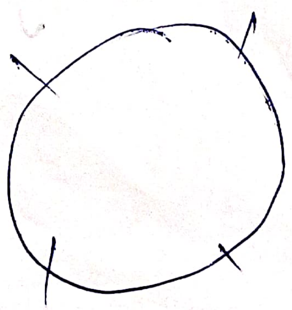
$$\Delta P = \left[\frac{\alpha v \mu_f v}{A^2} + \frac{R_m \mu_f}{A}\right] \frac{v}{t}.$$

$$\frac{t}{v} = \_\_ \quad \_\_$$

$\Rightarrow$ __ $v^2 + v$ __ $+$ __ $= 0$.

__ design A $\rightarrow$ filtration area.

$$A = \frac{\pi D^2}{4}.$$



$\longrightarrow$ $f \times A_T = A$.

t — filtration time.

$\frac{1}{n} \times f_R$

Unit operations by McCabe and Smith

→ Filtration.

① Laboratory filtration experiment is conducted at const press drop on a slurry of $CaCO_3$ in H_2O. Following data is observed filter area is 440 cm^2. Conc of solids in the slurry is 23.5 g/L of liq. temp^r is 25°C. Estimate α, R_m of the filter medium and cake.

→

~~t(s)~~	filtrate vol (V) (L)	t(s)
0.5	0.5	17.3
1	1	41.3
1.5	1.5	72
2	2	108.3
2.5	2.5	152.1
3	3.	

— 104

plot t/v v/s v.

$$c = \frac{c_f}{1 - \left[\left(\frac{m_F}{m_c}\right) - 1\right] c_s/\rho}$$

$$\frac{t}{V} = \left(\frac{K_c}{2}\right) V + \frac{1}{q_0}$$

$$\frac{1}{q_0} = \frac{\mu R_m}{A \Delta p g_c}$$

$$K_c = \frac{\mu c \alpha}{A^2 \Delta p g_c}$$

SV.

- Arithmetic normal distribution :- $y = \frac{d\phi}{dx} = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(x-\bar{x})^2}{2\sigma^2}\right]$.
- log normal distribution :- $y = \frac{d\phi}{d\ln x} = \frac{1}{\sigma_z\sqrt{2\pi}} \exp\left[-\frac{(z-\bar{z})^2}{2\sigma_z^2}\right]$.
- Rosin - Ramler - Bennet - Sperling formula.
  $\phi = \exp(-bx^n)$.
- Gates - Gaudin - Schumann. $F(x) = (bx)^n$.
- Gaudin - Meloy $F(x) = [1-(1-bx)^n]$
- Roller $F(x) = a\sqrt{x}\exp(-b/x)$..
- Svensson $F(x) = x\, E_p(\eta)$.

Optical microscope → theoretically 0.18 to 150 microns
Experimentally . 3 to 150 micron.

Limit of resolution $d = \frac{f\lambda}{NA}$.

f = factor = 0.6

λ = wave length.

NA = numerical aperture = $\mu \sin(\theta)$.

μ = refractive index.

Laser Diffraction:-

Rayleigh Scattering — particles smaller than wavelength.

Mie Scattering — particles larger than the wavelength.

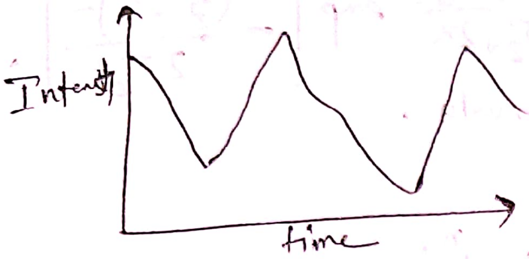
Rayleigh:- $I = I_0\left(\frac{1+\cos^2\theta}{2R^2}\right)\left(\frac{2\pi}{\lambda}\right)^4\left(\frac{m^2-1}{m^2+2}\right)^2\left(\frac{d}{2}\right)^6$.

Mie:- $I = E\left\{K^2D^4[J_1]^2\theta + (K_1\theta)^1 + (K_3\theta)^3 + (K_5\theta)^5 + \frac{K^4d^6(m-1)^2\theta^6}{8\pi}\right\}$.

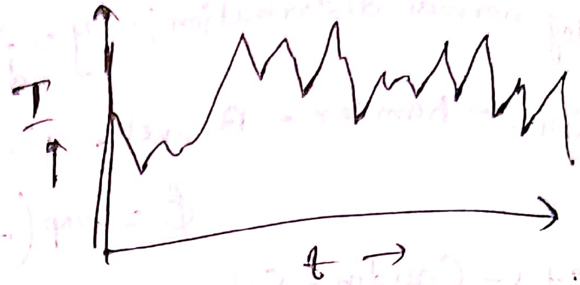
Scanned with OKEN Scanner

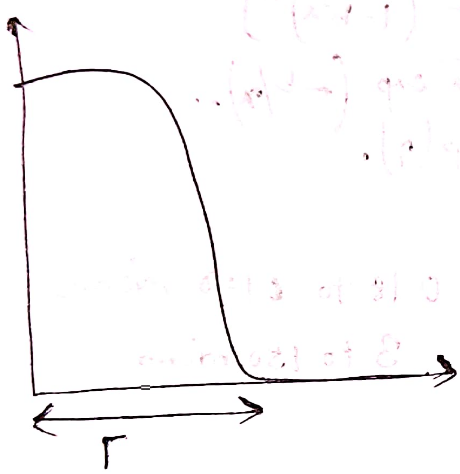
DLS :-

large particles.



smaller particles





$\Gamma = D_T q^2$

D_T = diffusion coeff

$q = \frac{4\pi n}{\lambda} \sin\frac{\theta}{2}$.

n = refractive index.

λ = wave length.

θ = scatter angle.

Einstein-Stokes Law :

Hydrodynamic diameter $D_h = \frac{k_B T}{6\pi \eta D_T}$

Bag Filter :-

Filtration vel $= \frac{\text{air}}{\text{cloth ratio}}$

Reverse Flow Cyclone Seperator :-

Cut particle diameter :- $d_{pc} = \left[\frac{9\mu B_c}{2\pi N v_i (\rho_p - \rho)}\right]^{1/2}$.

B_c = Inlet width.

N = effective no of turns (5-10 for common cyclone).

v_i = inlet gas vel (m/s).

ρ_p = particle density.

ρ = gas density.

Collection efficiency:-

$$E = \frac{1}{1+(d_{pc}/d_p)^2}.$$

Pressure drop:-

Shepard and Lapels equ^n:-

$$\boxed{\Delta P = 0.8\,\frac{\rho_g V_i^2 ab}{D_o^2}}.$$

$$N_e = \frac{1}{H} \times \left[L_c + \frac{Z_c}{2}\right].$$

N_e = no of turns inside the device.
H = ht of inlet duct
L_c = length of cyclone body.
Z_c = length (vertical) of cyclone cone

Electrostatic Precipitator:-

Necessary voltage:- $V = 18\left[1 + \frac{0.3}{R_1^{0.5}}\right] R_1 \ln\left(\frac{R_2^2}{R_1}\right)$ kV.

R_1 = radius of wire electrode.
R_2 = radius of collecting electrode.

velocity of collection particles:-

conducting particles:- $W = 0.16\left[\frac{d_p^2 V^2}{\mu}\right]$

non-conducting particles:- $W = 0.095\left[\frac{d_p^2 V^2}{\mu}\right]$.

Collection efficiency of particle:-

$$\eta = 1 - \exp\left(Q_g / w \cdot A_c\right).$$