29/7/24.

1. Air Pollution Vol 1: II, III Stern.
2. Pollution Control in Chemical & Allied Industries: S.P. Mahajan.
3. Waste water engg treatment & reuse: Metcalf & eddy
4. Env. engg: CS Rao.
5. Env. engg: GN Pandey & G.L. Carney.

→ Pollutant:

Assignment - 1:

1) what are the diff types of air pollutants emitted from chemical and allied Industries

CO_2, CO, PM_{10} $PM_{2.5}$, SO_2, NO.

& Harmful health effects.

10 pages
10th August
14th August.

→ WHO definition:

Four level of air pollution.

⇒ Based on. Conc & time of exposure.

Level - 1 : Conc & exposure time - (detectable)

Level - 2 : effect to sensory organs.

Level - 3 : ↓ of life time

Level - 4 : Casuality

30/7/24

→ Sources of SO_2 : 90% from coal.

→ Classification : S, L, G → Inorg / → Org.

→ Primary Pollutants → 1°ry pollutants
→ 2°ry pollutants.

1°ry pollutants : Source (direct) at chimneys.
Eg: SO_2, PM_{10}, SPM, NO_x.

1°ry pollutants $\xrightarrow[T,\, h\nu]{UV,\ sunlight}$ 2°ry pollutants.

→ Eg: $SO_2 + H_2O \longrightarrow H_2SO_3$.
$SO_2 + Air\,(O_2) + H_2O \longrightarrow H_2SO_4$.

→ National Ambient Air Quality Std (NAAQs)
↓ applicable to all.

8 hrs — PM_{10}, SO_2
24 hrs — $PM_{2.5}$, NO_x
Annual — CO

→ Stack emission standards

→ Standards → 1°
→ 2°

Load based conc — kg / MT of pdt.

Conc. based — mg/Nm³, ppm.

→ Existing power plant. — New plant
↓ large capacity — ↓ medium / small capacity.
medium/small

25 yrs back PM : 150 mg/Nm³.
20 yrs " : 100 mg/Nm³.
At present (from 2009) → 50 mg/Nm³.
→ 30 mg/Nm³.

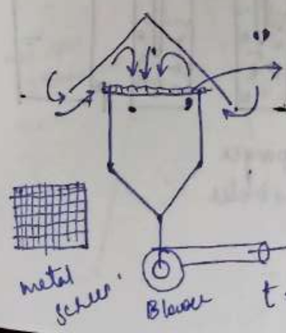
→ Std:
↓ 1°ry std — mainly for human health
2°ry std. — wild life / ecological purpose

→ Sampling & measurement of air pollution:

BIS : Bureau of Indian Std.
PM10, PM2.5, SO_2 ; CO, NO_x - std methods find out

→ Ambient air sampling.

Stack sampling.



→ Glass fibre filter paper (APM-325)
wt of filter paper = W_1.
Final wt of filter paper = W_2

t = 8 hrs, 24 hrs. For measuring flowrate of air → Rotameter.

Vol. flow rate $Q_1 = LPM_1 \times \Delta t$

$Q_2 = LPM_2 \times \Delta t$

$$Q_{av} = \frac{Q_1 + Q_2}{2}$$

Gram of dust collected over filter paper $= W_2 - W_1$

$$\text{Conc. of } PM_{10} = \frac{W_2 - W_1 \ g}{Q_{av} \times \Delta t \ \ lt} \qquad \frac{mg}{Nm^3}$$

$$\frac{Lt}{min} \times 24 \times 60\, min \qquad \frac{\mu g}{Nm^3}$$

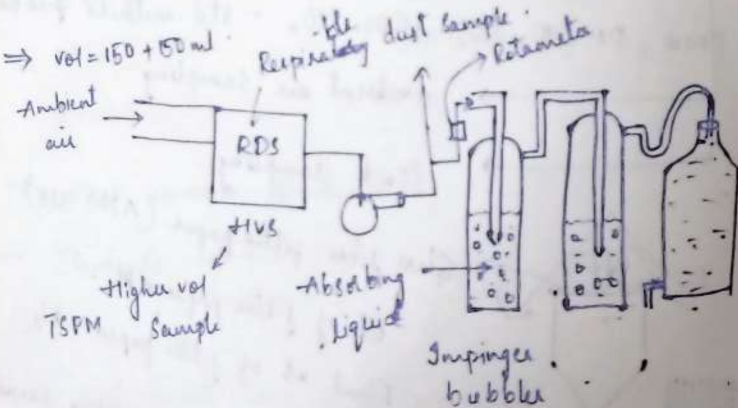
Q_{normal}:

Q_{av} at P T $\quad \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$

Size of filter : 8" × 10" (PM_{10})

For $PM_{2.5}$: circular 46 mm

⇒ vol = 150 + 150 ml



Volume = 150 + 150 ml.

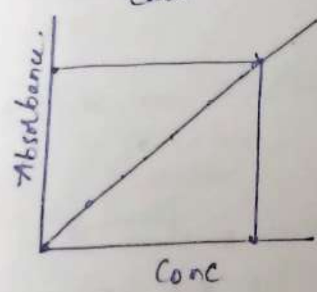
Tetrachloro mercurate soln

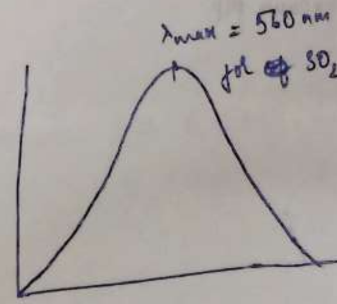
$\downarrow$

5 ml $\xrightarrow{diln}$ 500 ml.

· Rosaline hydrochloride. → light color.

UV-VIS Calibration curve.





Na_2S.

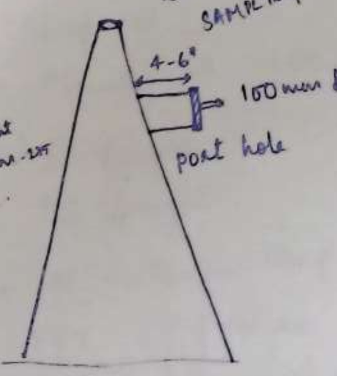
Prepare Na_2S $\qquad \frac{mg \text{ of } SO_2}{Q \times t = V}$.

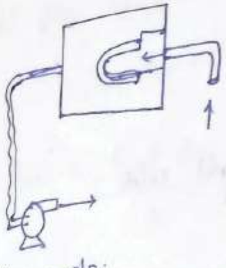
National Air Quality Ambient Quality Std : 80 μg/m³

→ Stack Sampling :

ISO-KINETIC SAMPLING

Height at Port hole : Min 2.5 times the located dia of chimney at 50 - 90 m.





Vacuum p/p

2/8/24:

→ EIA : Env. Imp Assessment

EMP : Env. Mng Planning.

→ SPCB :

CECB :

CPCC :

→ Take one Industry, prepare EIA & EMP. (25th Aug) 5-6 pages

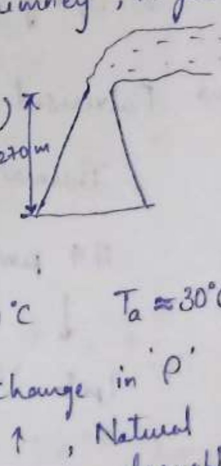
(local area)

200 km

- It should contains analysis
- New Ind setup?
- Mng plan : Socio-economic scenario.
- Sample report. : SPCB
- Select Industry
-

→ Transportation of Air Pollutants :

- when any air pollutant from chimney, it gets dispersed.
- Chimney ht : 270m (~1000 ft)



- ID draught

FD draught

- At particular temp : $T_g \approx 150°C$ | $T_a \approx 30°C$

$PM = \rho RT$ (↑ Hot air / ↓ Cold air) due to change in 'ρ', Hot air ↑, Natural draught

- Typical parameters on which dispersion depends
$P, T, H, \underset{(\text{vel of wind})}{v}, \underset{(\text{dirn of wind})}{\vec{V}}$

- Dry-Adiabatic Lapse rate :

Wind dirn : $S \rightarrow N$
Jar end $N \rightarrow S$

- Particulate Matter :

1) Dust :
2) Fumes : Metallurgical Industries.
Eg: Steel plant : BF brown cold fumes
3) Mist : Soluble gases + water
$\left.\begin{matrix} SO_2 + H_2O \\ SO_3 + H_2O \end{matrix}\right\}$ mist
4) Smoke : fine particles generated during Combustion
Incomplete / Partial Combustion $\Rightarrow CO$.
CO_2
5) Spray : Absorption process

→ Pulverised coal → Coal -200mesh .74 μm
Thermal coal : Ash content : 30-40 35%. (Indian)
11-16%. (Imported) coal

74 μm
↓ If particle size is < 30μm
1μm to 30 μm

Sulfur : 0.5%. (Indian coal)
Imported : 2.5%.

Gravity settler.
0.1 μm | 300 μm.
ESP 100 Cyclone separators
Bag houses

- Adiabatic Lapse Rate :

$P = \rho g h$

- $\frac{dT}{dh} = \frac{dT}{dP} \times \frac{dP}{dh}$

Air column

- As we go up, $T \downarrow$.

- $\frac{dP}{dh} = -\rho g \quad \because \rho = \frac{PM}{RT}$ for gases.

$\frac{dP}{dh} = -\frac{PM}{RT} g$. $\quad PV = nRT$

$\frac{P}{RT} = \frac{n}{V}$

$= -\frac{ng}{V} M$.

- Under adiabatic condition : $PV^{\gamma} = \text{const}$. $\gamma = C_p/C_v$.

$\frac{T}{T_0} = \left(\frac{P}{P_0}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{P}{P_0}\right)^{\frac{R}{C_P}}$

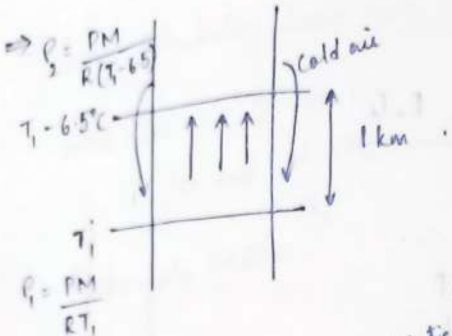
$T = T_0 \left(\frac{P}{P_0}\right)^{\frac{R}{C_P}}$.

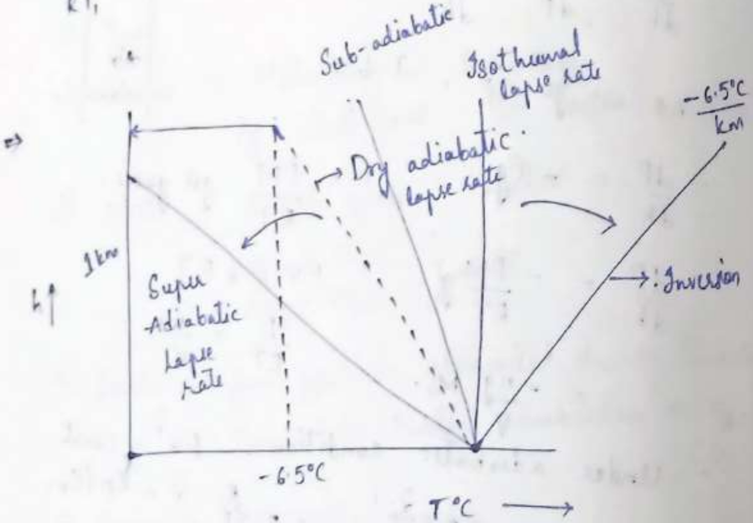
$\frac{dT}{dP} = \frac{RT}{PC_p}$.

- $\frac{dP}{dh} = \frac{dT}{dP} \times \frac{dP}{dh} = \frac{RT}{PC_p} \times \frac{-ngM}{V \cdot nRT}$

$\frac{dP}{dh} = -\frac{gM}{C_p} = -9.8\,°C/km$

$$\frac{dT}{dh} = -6.5°C/km.$$





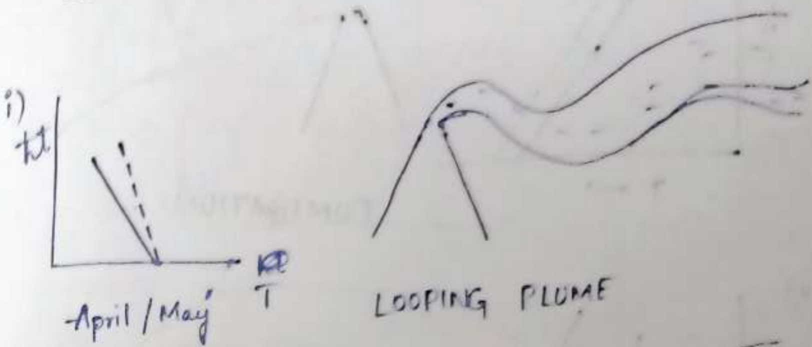
Inversion ?

① Radiation Inverse : The plume direction depends on this.
- After Sunset,

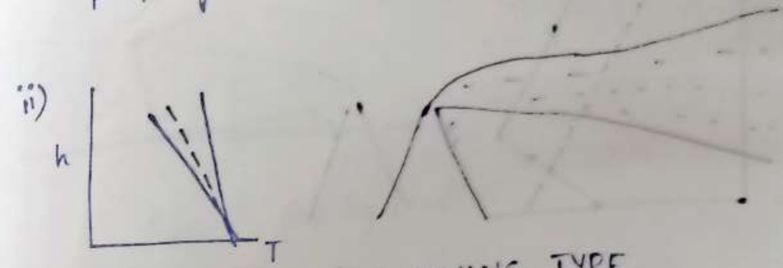
② (Anticyclone Inverse) | Subsidence Inversion

→ Impinger bubbles → Stack emission sample (???)

→ Plume Behaviour



LOOPING PLUME



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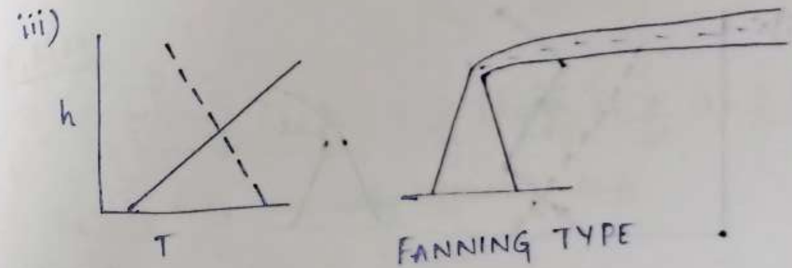

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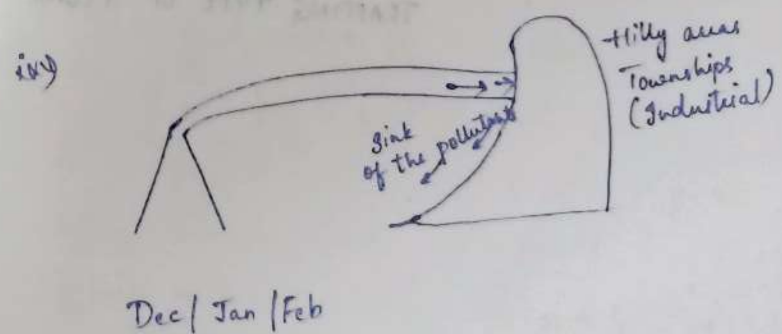
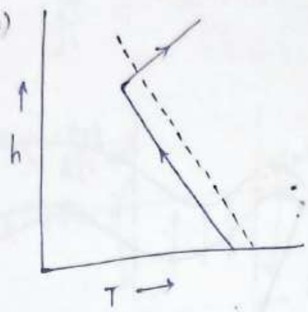
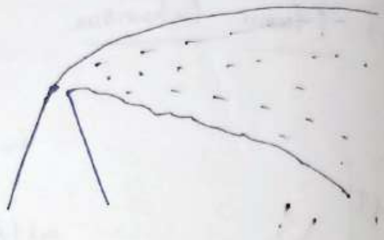


Dec / Jan / Feb

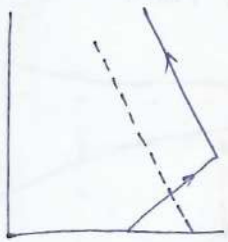
iv)





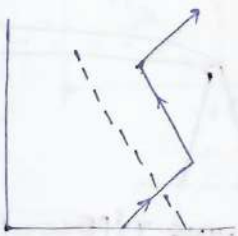
FUMIGATION.

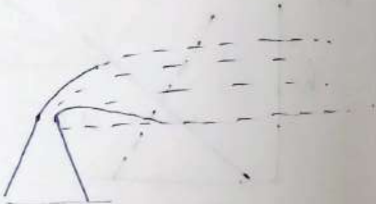
v)



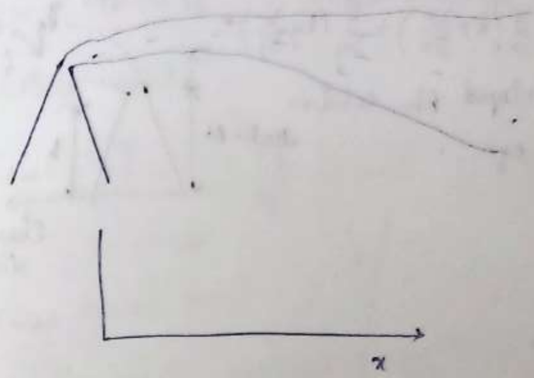
LOFTING.

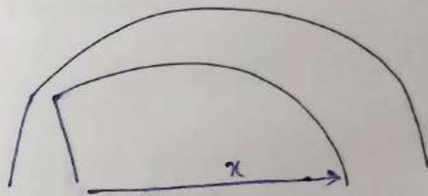
vi)





TRAPPING TYPE OF PLUME





$C_{x,0} = ?$

$C_{PM} = 300 \text{ mg}/Nm^3$.

Dispersion Modelling : Gauss —

6/8/24.

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(k_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_x \frac{\partial C}{\partial z}\right)$$

k_x, k_y & k_z are eddy diffusivity coeff.

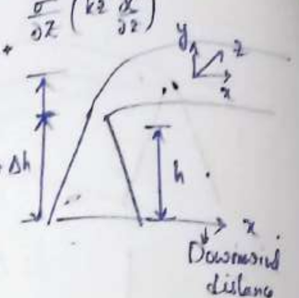
C

PRINTOUT ·

6/8/24 · Ficks law of turbulent diffusion

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(k_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial C}{\partial z}\right)$$

Gaussian developed the solution of model eqn ·



$Q_{x,y,z}$
↑
sink

$$C_{x,y,z,H} = \frac{Q}{2\pi u \sigma_y \sigma_z} e^{\frac{-y^2}{2\sigma_y^2}} \left[e^{-\frac{(z-H)^2}{2\sigma_z^2}} + e^{-\frac{(z+H)^2}{2\sigma_z^2}} \right]$$

with $z=0$ $$C_{x,y} = \frac{Q}{2\pi u \sigma_y \sigma_z} e^{-\frac{1}{2}\left[\frac{H^2}{\sigma_z^2} + \frac{y^2}{\sigma_y^2}\right]}$$

$$\boxed{C_{x,y} = \frac{Q}{\pi u \sigma_y \sigma_z} e^{-\frac{1}{2}\left(\frac{H^2}{\sigma_z^2}\right)} \cdot e^{-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2}\right)}}$$

C = conc· of pollutant in mg/m³

Q = emission rate of pollutants gm/s

U = mean wind velocity, m/s

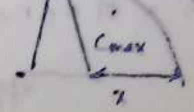
x, y = Downwind & cross wind distance in 'm'

σ_y = Plume std· variation in cross-wind direction 'm'

σ_z = Plume std· variation in down-wind direction

$H = h + \Delta h_v$ = Effective stack height ·

Townships should



C_{max} = ? $\frac{\sigma_y}{\sigma_z}$ => const

$\sigma_z = 0.707H$

(C_{max} occurs here)

→ Horizontal & vertical dispersion coeff's

log - log plot

→ $$C_{max} \quad C_{x,0} = \frac{Q}{\pi u \sigma_y \sigma_z} e^{-\frac{1}{2}\left(\frac{H^2}{\sigma_z^2}\right)}$$ ✓

At ground level ·

$$C_{x,0} = \frac{Q}{\pi u \sigma_y \sigma_z}$$

→ wind typically ↑es with ht & depends on the amount of solar radiation ·

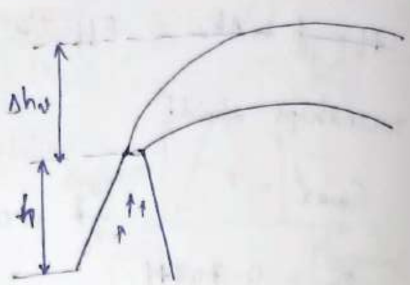
$$\frac{U_2}{U_1} = \left(\frac{z_2}{z_1}\right)^p \quad (z < 200\,m)$$

p depends on stability class (rural, urban) and 'surface roughness'

→ Eff. stack ht

$H = h + \Delta h_v$

eff.



$H = h + \Delta h_v$

$$\Delta h_v = \frac{v_s D}{u}\left[1.5 + 2.68 \times 10^{-3}\ P \cdot D \times \frac{(T_s - T_a)}{T_s}\right]$$

v_s = stack gas velocity.

D = Inside dia of stack at exit point, m.

u = wind speed at top of the stack / chimney m/s.

P = atm pressure in m.bar

T_s = stack gas exit temp K.

T_a = ambient temperature, K.

VALID ONLY FOR NEUTRAL PLUME.

→ BIS : no : 8829 - 1978.

a) For hot flue gases, with heat release rate $> 10^6$ cal/s

$$\Delta h_v = 0.84\ (12.4 + 0.09h) \times \frac{Q_H^{0.25}}{u}$$

b) For not very high heat rate

$$\Delta h_v = \frac{3 V_s D}{u}$$

→ i) $h = 74\ (Q_p)^{0.27}$ where Q_p = particulate emission rate Ton/hr.

2) $h = 14\ (Q_s)^{0.33}$

Q_s = SO_2 emission rate, kg/hr.

→ If the value is $h < 30$ m, as per std. ht give min stack height as 30 m

→ Minimum height :

a) Except thermal power plant & for rest of Industries = 30 m.

b) For thermal power plant

i) > 200 MW & < 500 MW - 220 m.

ii) > 500 MW - 275 m.

Q1) A ~~500 MW thermal power plant~~

Q1) A coal-fired thermal power plant burns 6.25T ~~6.5T~~ coal/hr and discharge the flue gas through the stack of eff. ht 80 m. The coal has a sulfur content of 4.7% & wind velocity of the gas at the top of chimney is 8 m/s. The stability of atm is moderately to slightly unstable. Determine the max ground level conc. of SO_2 and the dist from the stack at which it will occur.

Q. 4)

b) Cal the conc of SO_2 at a downwind distance of 1.5 km (along the centreline of the plume

Sol: Given : coal flow rate = 6.25 T/hr

Eff height of stack, H = 80 m.

Sulfur content in coal = 4.7%.

Mass of sulfur = $0.047 \times 6.25 \times 1000$

= 293.75 kg/hr.

wind velocity, u = 8 m/s.

a) C_{max} of SO_2 = ?

C_{max} occurs at $\frac{\sigma_y}{\sigma_z}$ const.

$\sigma_z = 0.707 \times 80 = \underline{56.56}$ m

$S + \frac{1}{2}O_2 \longrightarrow SO_2$

32 kg 32 kg O_2 64 kg SO_2

293.75 kg/hr 293.75 kg/hr × 2.

$\frac{293.75}{32} = \frac{x}{32}$ => $O_2^{th} = 293.75$ kg.

Assume 20% excess air

=> SO_2 emitted = 293.75 × 2 kg/hr = 81.597 g/s × 2
587.5

$Q_{SO_2} = \underline{163.1944}$ g/s

=> σ_y (for unstable)

0.9 km

σ_z (downward dist) = 0.75 km = 750 m

Corresponding σ_y from graph (at 0.75 km) = 90 m

=> $C_{max} = \frac{163.1944}{\pi \times 8 \times 90 \times 56.56} \times e^{-\frac{1}{2}\left[\frac{80^2}{(0.75 \times 1000)^2}\right]}$

=

=> σ_z (downward dist) = $\underline{0.9\text{ km}}$ = 900 m

σ_y from graph = 98 m.

$C_{max} = \frac{163.1944}{\pi \times 8 \times 98 \times 56.56} \times e^{-\frac{1}{2}\left[\frac{80^2}{900^2}\right]}$ $\frac{g/s}{\frac{m \times m \times m}{s}}$

= × 0.996

= $\underline{1.166 \times 10^{-3}}$ g/m³ = 1.166 mg/m³

=> Conc. of $\underline{SO_2}$ = 0.0017 mg/m³

12/8/24 .

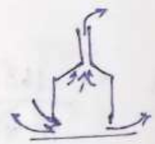
→ Nature of air emission :

1) Stack emission .

2) Fugitive emission .

$\bar{D}_p$ = μm

$$u_t = \frac{D_p^2 (\rho_p - \rho_g)}{18\mu}$$



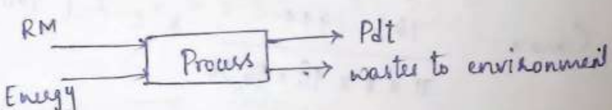
Capture velocity at hood = $2.5 \times u_t$:

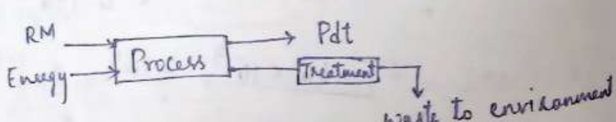
→ No. of hoods = n .

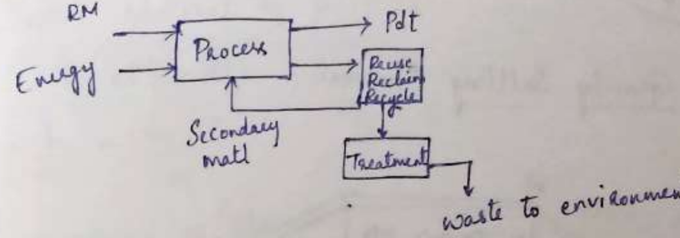
$Q = Q_1 + Q_2 + Q_3 + Q_4 + \dots\dots Q_n$

+ Head losses due to ducts

→ Industrial waste management practices :







ZLD - Zero liq discharge .

→ Source Reduction :

1) Product Change : a) Design for enviroment
b) Extend pdt life .

2) Process Changes : a) Matl change
b) Technology changes
c) Operational changes .

Alkylated HC instead of Triethyl lead : Octane no. improvement .

→ Particulate matter

Air pollution control eqpt

1. Gravity Settling Chamber
2. Cyclone separator
3. ESP
4. Bag houses

Gases (NH_3 , CO, SO_2 , SO_3 HC, H_2S) .

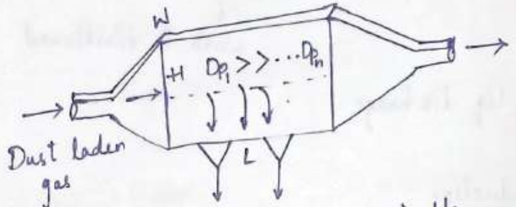
- wet scrubbers
1) - venturi scrubber
2) - Packed bed towers
3) - Spray towers .
4) Cyclonic scrubber
5) Tray towers
6) Bubble column scrubbers .

$\underbrace{\hphantom{xxxxxxxxxx}}$

These can be also be used for PM.

13/8/24.

→ Gravity Settling Chamber :



$Q = m^3/h.$

$v = \frac{Q}{A_{c/s}}$

Desirable Cond : Stokes law region for better eff.

↓

$$u_t = \frac{D_p^2 (\rho_p - \rho_g)}{18\mu}$$

At any time, $h = u_t \times t$

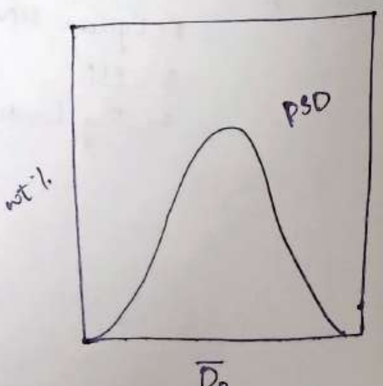
If $h > H$ they ~~don't~~ settle quickly :

$h < H$ particles will not settle down.

Eff : $\eta = \frac{h}{H} \times 100$

→

D_p (μm)	wt %
0 - 10	25
10 - 20	10
20 - 50	30.
50 - 100	
100 - 200	



For 100% removal of particles,

$$u_t \times t > H$$

$$\eta = \frac{h}{H} = \frac{u_t \times t}{H}$$

$$t = \frac{\text{volume of chamber}}{\text{capacity}} = \frac{HWL}{Q} = \frac{\cancel{HWL}}{\cancel{WH} \times v} = \frac{L}{v}$$

$$\eta = \frac{u_t \times t}{H} = \frac{u_t \times \frac{L}{v}}{H} = \frac{u_t \times L}{v \times H} = \frac{u_t \times L}{\frac{Q}{W\cancel{H}} \times \cancel{H}}$$

$$= \frac{u_t \times WL}{Q}$$

$$\eta = \frac{\frac{D_p^2 (\rho_p - \rho_g) g}{18\mu} \times WL}{Q} \quad \rho_g = ?$$

$$D_{p_{min}} = \left(\frac{18 \mu Q}{(\rho_p - \rho) g L W}\right)^{1/2} \text{ if } \eta = 1.$$

$$D_{p,100} = \left[\frac{18 \mu Q}{(\rho_p - \rho_g) g L W}\right]^{1/2}$$

→ $D_{p,50}$ = It means the eff. of the particles of that size to size is 50%.

→ i) For laminar flow

$$u_t = 0.003\, \rho_p\, D_{p,\mu m}.$$

↑ kg/m³ ↑ μm.

2) Intermediate region :

$$u_t = f(N_{Re}, D_p, \rho_g)$$

3) Turbulent region :

$$u_t = \left[3 \rho_p g \frac{D_p}{\rho_g} \right]^{1/2}.$$

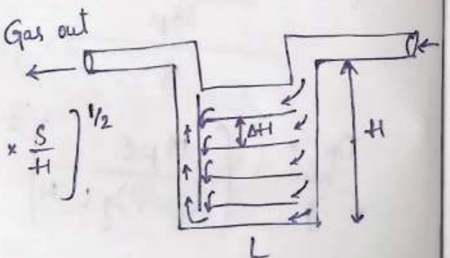
Adv & disad of Gravity Settling Chambers :

- Cost is low — low eff
- Maintenance is low — huge space

→ Multi - Tray Gravity Settling Chamber :

ΔH = tray spacing.

$$D_{P,min} = \left[\frac{18 \mu Q}{(\rho_p - \rho_g) g W L} \times \frac{S}{H} \right]^{1/2}.$$



Q : A contaminated gas stream @ ~~600~~ 657.89 m^3/min passed through a gravity settling chamber for abatement of particle pollution. The drive sieve analysis shows dust producing 30 - 130 μm. It has been decided by the industry to maintain the emission std of particulate matter as per pollution control board, Above 100 μm particle must be removed by simple gravity settling chamber. Design the settling chamber and the collection efficiency for interrange of particle size. The temp of gas stream 20°C.

Density of particle = 2.7 g/cc

viscosity of gas 0.0176 cP.

Sol: Thumb rule for gravity settling chamber. $H : W : L = 1 : 2 : 3$

Given : $Q_{gas} = 657.89 \ \frac{m^3}{min}$.

Design : H, W, L,

$$D_{P_{min}} = \left[\frac{18 \mu Q}{(\rho_p - \rho_g) g W L} \right]^{1/2}.$$

$$\rho_g = \text{density of air} = \frac{PM}{RT} = \frac{1 \text{ atm} \times 28.84 \ \frac{kg}{kmol}}{0.0824 \ \frac{atm \cdot m^3}{kmol\ K} \times 293}$$

$$\rho_g = 1.19 \ \frac{kg}{m^3}$$

$$D_{P_{min}}^2 = \frac{18 \times 0.0176 \times 10^{-3} \times \frac{657.89}{60}}{((2.7 \times 10^3) - 1.19) \times 9.8 \ WL}.$$

$(100 \times 10^{-6})^2$

$$WL = 13.133$$

$H : W = 1 : 2$ $\quad \frac{H}{W} = \frac{1}{2}$

$H : L = 1 : 3$ $\quad \frac{H}{L} = \frac{1}{3}$

$$2H \times 3H = 13.133$$

$$6H^2 = 13.133$$

$$H^2 = 2.1889 \qquad H = 1.4795 \ m$$

$W = 2.9589\ m \qquad L = 4.4385\ m.$

~~Ex~~ Overall eff

$$\eta_T = \eta_1 W_1 + \eta_2 W_2 + \dots\dots + \eta W_n .$$

$\Rightarrow$ Residence time,

$$t = \frac{HWL}{Q} = \frac{1.4795 \times 2.9589 \times 4.4385}{\frac{657.89}{60}}$$

$$t = \cancel{1.7725}.\ \underline{1.8\ s}$$

$$\Rightarrow \text{velocity} = u_t = \frac{Q}{A_{c/s}} = \frac{657.89/60}{2.9589 \times 1.4795}$$

$$= 2.5\ m/s$$

$$\Rightarrow h = u_t \times t = 4.5\ m.$$

$$\Rightarrow \boxed{\eta_i = \left(\frac{D_P}{D_{P,min}}\right)^2 \times 100.}$$

Q: The following particle size distribution is obtained from the particles which are obtained by using a gravity settling chamber.

D_P range	wt (gm)
<5	2
5 - 10	2
10 - 15	4
15 - 20	7
20 - 30	10
30 - 35	~~10~~ 8
35 - 40	~~8~~ 7
40 - 50	~~7~~ 10
50 - 60	~~10~~ 15
60 - 70	~~15~~ 20
>70	10

i) Calculate overall eff assuming D_{P100} is 40μm.

Q3: Sulfuric acid sprayed in air at 35°C at 1.0 atm is to removed by simple gravity. The unit is 3 m × 6 m × 9 m (H × W × L). The volume flow rate of gas 3000 m³/h. The sp.g of mist is 1.24 and μ_{gas} = 0.018 cP. Calculate the i) smallest size of the spray that can be completely removed

ii) D_{P50} = ?

iii) If flow rate is ↑ed by 3 times to that of present what is the $D_{P_{min}}$?

$D_{P_{min}}$ $D_{P_{50}}$ Q_{min} $3Q_{old}$

Sol

Q3: A coal burning power plant burns 50000 TPD of coal and an ESP is used to collect the fly ash from power plant with an working eff of 99.5% The coal has a sulfur content 0.6% and total amount of fly ash generated is 5 kg / ton of coal burnt. The physical stack height is 150 m and inside dia is 1.5 m. The stack gas leaves at 130°C The ambient temp is 30°C and barometric pressure of 925 millibars. A moderately unstable plume is found at the exit of the chimney. The wind velocity measured at 6m height from the ground and avg. wind velocity recorded as 3 m/s The value of exponent p for various stability classes given below.

Stability Class	A	B	C	D	E	F
Rural	0.07	0.08	0.1	0.15	0.35	0.55
Urban	0.15	0.17	0.2	0.25	0.3	0.35

Calculate :

i) eff stack height.

ii) The max. conc of SO_2 and how far is this from the plant. Does this plant by itself causes conc. in excess of the annual ambient air quality standards?

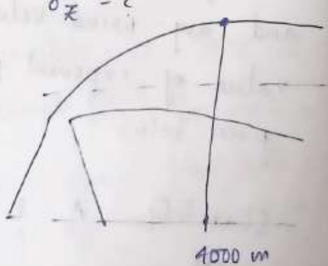
iii) The conc. of SO_2 at a distance of 4.0 km with a crosswind dist. of 100 m on either side of the plume central line.

iv) The max conc. of fly ash and how far is this from the plant.

v) Fly-ash conc. profile upto a distance of 10 km from the stack.

iii) $x = 4000\,m$ $\sigma_y = ?$ $\sigma_z = ?$

$y = 100\,m$



iv) Q_{max}, pm

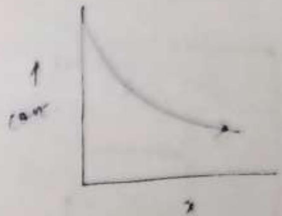
$\sigma_z = 0.707H$

$x = ?$

$\sigma_y = ?$

v) $x = 1, 2, 3 \ldots$ $\sigma_y = ?$ 10 km

$x = 2000, 4000, 6000$

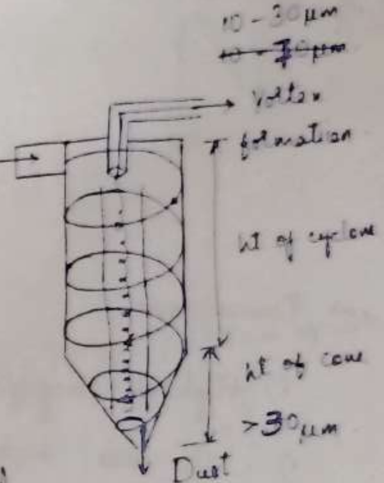


19/8/24.

→ Cyclone Separator

If particulate matter is 10 - 100 μm

Min velocity for cyclone - sep, $v = 15\,m/s$.



→ They may be connected in

i) Parallel - Majority we use this

ii) Series

→ 80% PM - sep

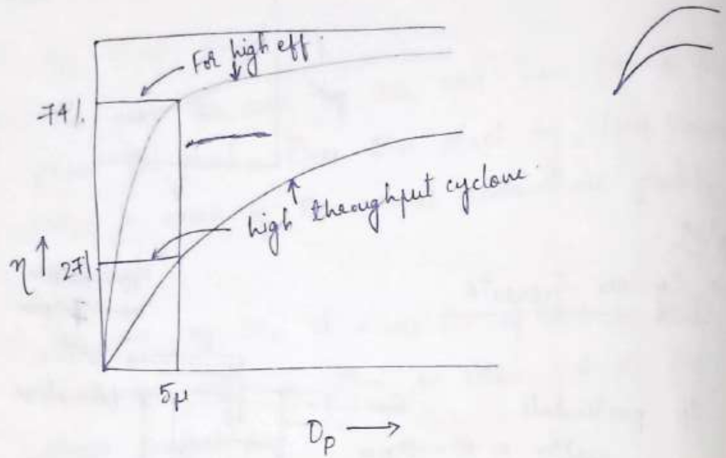
20% PM → Bag filter, ESP

→ There are two types of cyclones.

i) High eff. cyclone.

ii) High throughput cyclone.

i) In case of high eff cyclone



$\Rightarrow$ Dimensions :

	i) High efficiency cyclone	ii) High throughput cyclone
1) I/L area = $b \times h$		
b = entrance width	$b = 0.2D$	$b = 0.375D$
h = entrance ht.	$h = 0.5D$	$h = 0.75D$
2) Diameter of cyclone	$= D$	D
3) Dia of exit gas	$= 0.5D$	$0.75D$
4) Dia of exit tube	$= 0.5D$	$0.875D$
5) Height of cyclone	$1.5D$	$1.5D$
6) Height of cone	$2.5D$	$2.5D$
7) Diameter of dust collector	$\frac{3}{8}D$	$\frac{3}{8}D$

8) $Q = 223\, m^3/hr$ $\quad$ $Q = 669\, m^3/hr$

Dia = 203 mm $\quad$ Dia = 203 mm

$v = 15$ m/s $\quad$ $v = 15$ m/s

$\rightarrow$ $$D_{P,c} = \left[\frac{9\,\mu_f\, b}{2\pi N v(\rho_p - \rho_g)}\right]^{1/2}$$

$D_{P,min}$

$$D_{P,\,min} = \left[\frac{9\,\mu_f\, b}{\pi N v(\rho_p - \rho_g)}\right]^{1/2}$$

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$\rightarrow$ Pressure drop across the cyclone : (100 cm of water)

$$\Delta P = \frac{\rho_F}{203}\left[u_1^2\left[1 + 2\phi^2\left(2\frac{r_t}{r_e} - 1\right)\right] + 2u_2^2\right]$$

where ΔP = pressure loss in millibar.

ρ_F = density of gas, kg/m³

u_1 = Inlet duct velocity of gas, m/s

u_2 = outlet duct gas velocity, m/s

r_t = Radius of circle to which the central line of inlet gas is tangential, m.

r_e = Radius of exit pipe, m.

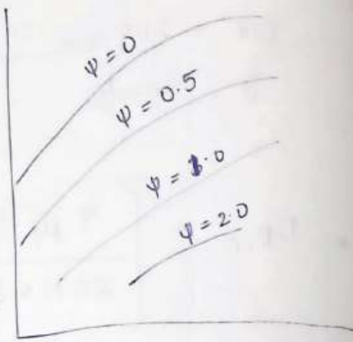
$$\phi = f\left(\psi, \frac{r_t}{r_e}\right)$$

$\psi = \dfrac{f_c \cdot A_s}{A_1}$

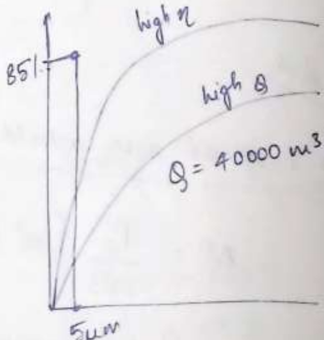
f_c = friction factor

A_s = surface area, m^2

A_1 = Area of I/L duct, m^2.



D_p range	wt%	$\bar{D}_p$
0 - 2	5	1
2 - 4	10	3
4 - 6	15	5
6 - 10	20	8
10 - 50	.	30
50 - 100	.	75
>100	.	100



$$\frac{40000}{3600} = Q = b \times h \times \bar{v}$$
$$= 0.2\,D_c \times 0.5\,D_c \times 15 \text{ m/s}$$

$$\Rightarrow \text{Scale-up factor} = \frac{D_2}{D_1} = \left[\left(\frac{D_{c_2}}{D_{c_1}}\right)^3 \times \left(\frac{Q_1}{Q_2}\right) \times \left(\frac{\Delta\rho_1}{\Delta\rho_2}\right) \times \left(\frac{\mu_2}{\mu_1}\right)\right]^{1/2}$$

D_1 = mean ~~value~~ diameter of particle separated at std. condition at the chosen separation efficiency i.e., high eff η & high throughput design. Cyclone.

D_2 = mean dia of the particle separated at the same efficiency for proposed ~~desio~~ cyclone design

D_{c_1} = dia of standard cyclone 203 mm.

D_{c_2} = dia of cyclone for proposed design.

Q_1 = Capacity of standard cyclone

for high η = 223 m^3/h.

for high throughput = 669 m^3/h.

Q_2 = capacity of proposed cyclone, m^3/h.

$\Delta\rho_1 = (\rho_p - \rho_f)$ at standard condition = 2000 kg/m^3

$\Delta\rho_2 = (\rho_p - \rho_f)$ of proposed gas to be handled for proposed cyclone.

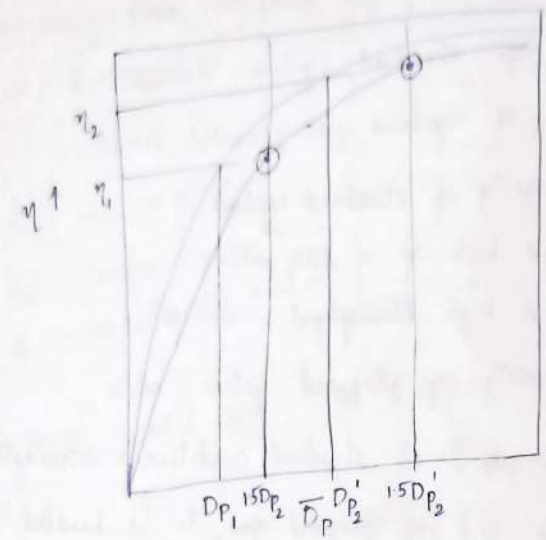
μ_1 = test gas viscosity 0.018 cP (Air at 20°C & 1 atm pressure)

μ_2 = viscosity of gas to be handled in the proposed design.

$\Rightarrow$ let's assume $\frac{D_2}{D_1} = 1.5 \Rightarrow D_2 = 1.5\,D_1$

Assume

$\bar{D}_{p_1}$	1	D_2	1.5
$\bar{D}_{p_2}$	3	D_2	4.5
$\bar{D}_{p_3}$	5	D_3	= 7.5
$\bar{D}_{p_4}$	8	D_4	= 12



$\frac{D_2}{D_1}$ $\frac{D_{p_2}}{D_{p_1}}$

$$\eta_i = \frac{\left(\frac{d_p}{d_{pc}}\right)^2}{1+\left(\frac{d_p}{d_{pc}}\right)^2} \times 100 = \sum \eta_i W_i$$

→ Cyclone parameters:

Increase in	Effect on η
Sp.g of dust	↑
Gas viscosity (T)	↓
Dust surface area	↓
Dust loading	↑
Inlet velocity	↑

Geometry of cyclone

Increase in cyclone dimension	η
I/L area (b×h)	↓
Cylindrical length	↑
Cone length	↑
Cyclone dia	↓
Vortex finder dia	↓
Vortex finder depth	↑

$\Rightarrow Q_{New} = Q_1 = \frac{Q}{2}$ $\quad D_p$

$Q_2 = \frac{Q}{4}$

Problem

The particle size distribution of cement plant is given below:

Particle size range (µm)	wt	$\overline{D}_p$
0 - 2.5	15	
2.5 - 5	8	
5 - 10	12	
10 - 20	13	
20 - 30	17	
30 - 40	14	
>40	21	

i) If a certain cyclone is having a cut size particle diameter 9 μm. what will be the overall collection efficiency.

ii) Find out the $D_{p_{min}}$ from the efficiency chart generated.

Sol:

$D_p(\mu m)$	$\bar{D}_p$	wt	wt %	η_i	$\eta_i w_i$
0 - 2.5	1.25	15	15	1.89	0.2835 ~~2.5515~~
2.5 - 5	3.75	8	08	14.7928	1.183424
5 - 10	7.5	12	12	40.9836	4.918032
10 - 20	15	13	13	73.5294	9.558822
20 - 30	25	17	17	88.5269	15.04957
30 - 40	35	14	14	93.7978	13.13169
> 40	40	21	21	95.1814	19.988094
		100			

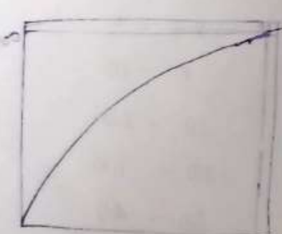
$\eta_1 = \sum \eta_i w_i = 64.1131$

i) $$\eta_i = \frac{\left(\frac{d_p}{d_{p_c}}\right)^2}{1 + \left(\frac{d_p}{d_{p_c}}\right)^2} \times 100$$

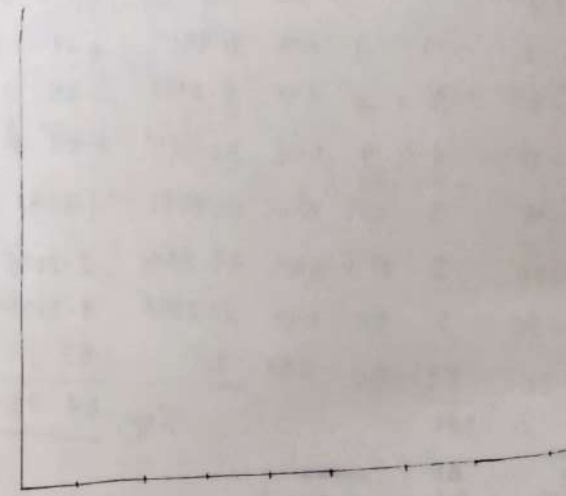
85

ii) $\bar{D}_p$ vs η_i

η



$\bar{D}_p$ $\quad$ $D_{p_{min}}$



Problem 2: The particle size distribution of emitted dust from an incineration plant is given as following table. The vol. flow rate is 4800 m^3/hr what will be the overall collection eff of conv. cyclone with a cut size par 10 μm is used. If the max allow pressure drop of 127 mm of H_2O. what should be the dimensions of cyclone assume ΔP is 8 times velocity head

(a)

D_p (μm)	wt	$\bar{D}_p$	wt	η_i		$\eta_i w_i$
0-3	17	1	0.17	0.990	0.17	0.1683
3-8	5	3	0.05	8.2518	0.05	0.4126
8-10	8	7	0.08	33.8857	0.08	2.6308
10-15	3	12.5	0.03	60.9756		1.8292
15-20	3	17.5	0.03	75.3846		2.2615
20-30	5	25	0.05	86.2068		4.31034
>30	59	30	0.59	90		53.1
	100				$\Sigma \eta_i w_i =$	64.71298

$$\frac{\Delta P}{\rho_g L} = 8 \frac{v^2}{2g}$$ 91

Let $\frac{127\ mm\ H_2O}{1000} = 8 \times \frac{v^2}{2 \times 9.8}$ ✗

$v = 0.5578\ m/s$

$\Rightarrow Q = v \times 1/2$ area. $Q = v \times 0.375 D \cdot D$

$\frac{4800\ m^3}{3600} = 0.5578 \times b \times h$ $D = 1.177$

$2.39034 = 0.2D \times 0.5D$

$D = 4.889\ m$

$b = 0.9778\ m$

$h = 2.444\ m$

$\rho_g = \frac{PM}{RT} =$

$\rho_1 g_1 h_1 = \rho_2 g_2 h_2$ h_2 = air column

$1000 \times 0.127 = \rho_2 \cdot 1.25 \times h_2$

$h_2 =$

23/8/24

$\frac{10}{10^3 \times 10^3}$

①. Design a cyclone separator to handle 3600 m^3/h of gases containing the gypsum dust of 2.0 g/cc at a temp of 80°C emitted at a gypsum plant. The no of turns which the cyclones completes is 5. Density of gas 0.95 kg/m³. viscosity of gas 0.025cP. The pressure loss in the cyclone is 8 times velocity head and is 7.5cm of H_2O. The particle size distribution is as follows:

D_p	wt
< 5	15
5 - 10	15
10 - 30	30
30 - 50	25
> 50	15

Calculate the collection overall efficiency of designed cyclone. If 20 cyclones of equal size (multisize cyclones) are used to handle gas. Determine the dimensions & efficiency of the cyclone separator. Assume that the head available in the multicyclone to be 10% less than that of single unit.

$$\eta_1 = \frac{\left(\frac{d_p}{d_{pc}}\right)^2}{1 + \left(\frac{d_p}{d_{pc}}\right)^2} \times 100$$

Sol: 5 µm

$\bar{D}_p$ range	wt	$\bar{D}_p$	wt (w_i)	η_i	$\eta_i w_i$	
< 5	15	2.5	0.15	0.364	0.0546	1.896 ~~5.46~~
5-10	15	7.5	0.15	0.5628	0.08442	8.442
10-30	30	20	0.3	0.9015	0.27045	27.045
30-50	25	40	0.25	0.9734	0.24335	24.335
> 50	15	50	0.15	0.9828	0.14742	14.742

$\sum \eta_i w_i =$ ~~80.034~~ 76.46

$\Rightarrow Q = 3600\ m^3/h = 3600 \times 1000 \times 1000\ cm^3/h$

$\rho_{gas} = 0.95\ kg/m^3 = 0.00095\ g/cc$

Head loss across the cyclone $= 7.5$ cm of H_2O $\frac{\cdot 1}{0.00095}$

$\rho_g g h_g = \rho_{H_2O} g h_{H_2O}$

$0.00095 \times h_g = 1 \times 7.5$

$h = 78.94m$

$= 8$ times velocity head

$= 8 \times \frac{\bar{v}^2}{2g}$

$\bar{v} = 13.91\ m/s$ ~~44.4261 cm/s~~

$\Rightarrow b \times h \times \bar{v} = Q$

$0.2D \times 0.5D \times 13.91$ ~~44.4261~~ $= \frac{3600}{3600} \times 10^6\ \frac{m^3}{s}$

$D^2 = 0.7189$ ~~28466.37~~ cm

$=$ ~~28.466 m~~

$D = 0.847 \simeq 0.85m$

$$D_{P_c} = \left[\frac{9\,\mu_f\, b}{2\pi N v\,(\rho_p - \rho_g)}\right]^{1/2}$$

$$= \left[\frac{9 \times 0.025 \times 0.001 \times 0.2 \times 0.85}{2\pi \times 5 \times 13.91\,(2\times10^3 - 0.95)}\right]^{1/2}$$

$D_{P_c} = 6.61\ \mu m$.

ii) $Q = 3600\ \frac{m^3}{hr}$. no. of cyclones = 20

$$Q_{new} = \frac{Q}{20} = \frac{3600}{20} = 180\ \frac{m^3}{hr}.$$

$$\Delta P_{old} = 8\frac{\bar{v}^2}{2g}.$$

$h_g \rho_g = h_{H_2O}\,\rho_{H_2O}$

$h_g \times 0.95 = 7.5\times10^{-2} \times 1000$

$h_g = 78.94$ m.

Now $\frac{8\bar{v}^2}{2g} = 7.5\text{ cm} \times 0.9$.

$h_g = 78.94$m

$$\Rightarrow\ 78.94 \times 0.9 = 8\frac{\bar{v}^2}{2g}$$

$$\bar{v} = 13.193\text{ m/s} \simeq 13.2\text{ m/s}.$$

$$\Rightarrow\ b \times h \times \bar{v} = \frac{180}{3600}$$

$$0.2D \times 0.5D \times 13.2 = \frac{180}{3600}$$

$D^2 = 0.0378$ m $D = \underline{0.1946}$ m

$$D_{P_c} = \left[\frac{9\,\mu_f\, b}{2\pi N v\,(\rho_p - \rho_g)}\right]^{1/2}$$

$$= \left[\frac{9 \times 0.025 \times 0.001 \times 0.2 \times 0.1946}{2\times\pi \times 5 \times 13.2 \times (2000 - 0.95)}\right]$$

$= 3.25 \times 10^{-6}$ m $= 3.25\ \mu m$.

$\bar{D}_p$	w_i	η_i	$\eta_i w_i$
2.5	0.15	37.1747	5.5762
7.5	0.15	84.19	12.6285
20	0.3	97.427	29.2281
40	0.25	99.344	24.836
50	0.15	99.5792	14.9368
			87.2056

For std cyclone, high eff the $Q_{std} = 223\ m^3/h$.

③. A multitray settling chamber having 8 trays including bottom surface handles 6 m³/s of air at 20°C. The tray are spaced 25 cm apart and the chamb 1m wide & 4m long. The density of particle is 2000 kg/m³. i) Calculate the min particle diameter that can be collected by the settling chamber ii) what will be the eff. of settling chamber if 50 μm particle are to be removed considering laminar flow region.

Viscosity of gas $\mu_g = 1.81 \times 10^{-5}$ kg/m s

Neglect density of gas in comparison to particle.

$g = 9.81$ m/s^2

Sol:
$$D_{P,min} = \left[\frac{18\mu Q}{(\rho_p - \rho_g) g WL} \times \frac{S}{H}\right]^{1/2}$$

$$= \left[\frac{18 \times 1.81 \times 10^{-5} \times 6}{(2000-0) \times 9.8 \times 1 \times 4} \times \frac{25 \times 10^{-2}}{8 \times 25 \times 10^{-2}}\right]^{1/2}$$

$$= 0.5582 \times 10^{-6}$$
$$= 5.582 \times 10^{-5}$$
$$= 55.82 \times 10^{-6} = 55.82\ \mu m.$$

ii) $$\eta_i = \left(\frac{D_P}{D_{P_{min}}}\right)^2 \times 100 = \left(\frac{50\mu m}{55.82\mu m}\right)^2 \times 100$$
$$= 80.237\ \%.$$

(4). A conventional cyclone of diameter of 500 mm is used to treat the flue gas containing cement dust particulate of 3.5 g/m³ at 165°C and 1 atm. The inlet gas velocity is 17 m/s and no. of turn the gas completes in cyclone is 5.

Data: Density of particle and gas 2700 kg/m³, 1.04 kg/m³.

Viscosity of gas = 0.019 cP.

The particle size distribution are as follows:

Particle size (μm	% wt
> 50	19.5
50 - 40	10.0
40 - 30	7.5
30 - 20	15
20 - 15	21
15 - 10	15
10 - 5	9.5
< 5	2.5

$$\eta = \frac{C_{in} - C_{out}}{C_{inlet}} \times 100$$

Calculate:
1) cut size dp
2) Overall collection eff
3) Overall dust conc. from cyclone

Trial n used eff. table.

(5). Design a cyclone separator to remove dust particles from a contaminated gas stream. The particle size distribution is given below. The gas is essentially air at 150°C and density of particle and gas are 2000 kg/m³ & 1.05 kg/m³ resp. The flow rate of gas to be handled is 30000 m³/hr and the cyclone operate at 1.06 kg/cm² pressure. Emission limit consideration gives 82% of dust must be removed

$\mu_g = 0.0116$ cP.

Particle size range (μm)	>50	40-50	30-40	20-30	15-20	10-15
wt %.	5.5	6.0	7.5	15	7.0	15

5-10	2-5	0-2
9.5	30.5	4.0

⑥. A conventional cyclone of diameter of 1.5m is used to treat the flue gas containing particulate of 3200 mg/m³ at 175°C and 1atm. The I/L gas velocity is 17.4 m/s & no. of turn in the cyclone is 5. Data : Density of particle is 2350 kg/m³ viscosity of gas = 0.0118 cP.

Calculate :

i) Cut size particle dia ii) Overall collection eff of the cyclone.

Particle size distribution.

D_p (μm)	>50	50-40	40-30	30-20	20-15	15-10	10-5	<5
wt %.	35	15	20	9	6	5	6	4

⑦. A coal burning power plant burns 24000 TPD. The coal has a sulfur content of 1.7%. The physical stack height, h is 20

& h = — m.

c) 0.5 1.15

3/9/24.

→ Filtration vel = $\frac{Q}{A}$ m/min)

→ Filtration time:

At const pressure filtration.

t_f = filtrate time

ΔP = pressure drop of thickness Δz

V_G = vol. of gas filtered.

$$t_f = \frac{B}{2\Delta P} V_G^2 + \left(\frac{C}{\Delta P}\right) V_G .$$

where B & C are const and experimentally found

If resistance of filter media is negligible.

$$t_f = \frac{B}{2\Delta P} V_G^2$$

B : Const rate filtration, Q = constant.

$\Delta P = BQ^2 + CQ$

t = time of filtration.

Q = volumetric gas flow rate.

At $t = 0$ $\quad \Delta P = CQ$.

$t = t$ $\quad \Delta P = BQ^2 + CQ$

$$t = \frac{BV_G^2}{2\Delta P} + \frac{DV_G^2}{\Delta P}.$$

$\Delta P = (BV_G + D)Q$.

* Const Capacity filters used.

→ Types of bags :

1) flat cylindrical.
2) pleated - area is 3-4 times > flat cylindrical bag

→ Air to cloth ratio = $\frac{m}{min}$ (≈ 2.5)

$$\frac{Q \text{ (in } m^3/min)}{A, \text{ Total surface area } (m^2)}$$

Surface area of bag = $\pi DL + \frac{\pi D^2}{4}$

No. of bags = $\frac{\text{Total surface area}}{\text{Area of one bag}}$.

→ Arrangement of bags : 1) Rectangular 2) Triangular. 3) Square.

→ $$Q = \frac{V_G}{t_f + t_c}$$

when $t_c = 0$ then $Q = Q_{max}$.

Assume $t_f = t_c$ to get optimized capacity of the bag house.

→ Max ΔP in the bag filter = 100 cm ~~H_2O~~ WC

ΔP in the new bags = 50 - 60 cm ~~H_2O~~ WC

→ Reasons for the cake formation (clay layer) which leads to ↑ in ΔP ↓ leads to rupture of bag filter.

1) high humidity
2) Material hygroscopic.
3) Due to rain,

→ Bag rupture can be identified

1) ΔP sudden decreases
2) outlet dust conc ↑es.

→ $$\eta = \frac{C_{inlet} - C_{outlet}}{C_{inlet}} \times 100$$

C_{inlet} = 3000 mg/Nm³

C_{outlet} = 30 mg / Nm³

$\therefore \eta >> 99\%$.

Q: Thumb rule: Bag filters should be used where temp of operation is close to ambient

Q: Design a cyclone sep to remove a dust particulate matter from a contaminated gas stream. The particle size distribution in the gas stream is below. The gas passes through the bag houses @ 4000 m³/hr at 1 atm at a temp of 150°C. The density of the particle is 2500 kg/m³. Emission limit consideration restricts that 80% of the solids must be removed from the cyclone separator.

Particle size (μm)	50	40	30	20	10	5	2
% by wt less than	90	86	80	70	45	25	10

ii)

Sol:

Particle size (μm)	% wt less than	Particle size	wt % $\bar{D}_p$	wt %. η_i
50	90	>50	50	10
40	86	40-50	45	90-86=4
30	80	30-40	35	86-80=6
20	70	20-30	25	80-70=10
10	45	10-20	15	70-45=25
5	25	5-10	7.5	45-25=20
2	10	2-5	3.5	25-10=15
		<2	1	10

High efficiency cyclone

$$Q = b \times h \times v \qquad b = 0.2D$$

$$h = 0.5D$$

$$\frac{4000}{3600} = 0.2D_c \times 0.5D_c \times v \qquad v = 15\ m/s$$

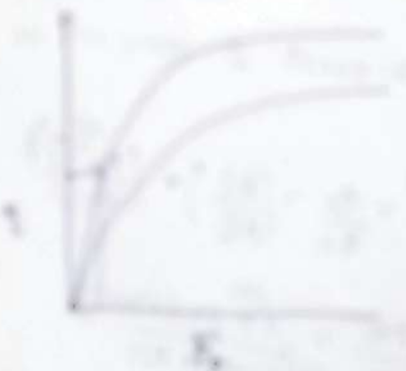
$$D_c = 0.86\ m.$$

⇒ Assume $\mu = 0.023\,cP$ at $150°C$.

$$\frac{d_2}{d_1} = \left[\left(\frac{Dc_2}{Dc_1}\right)^3 \times \frac{Q_1}{Q_2} \times \left(\frac{\Delta P_1}{\Delta P_2}\right) \times \left(\frac{\mu_2}{\mu_1}\right)\right]^{1/2}$$

$$\Delta P_2 = \rho = \frac{PM}{RT} = \frac{1\ atm \times 28.84\ kg/kmol}{0.082\ \frac{atm\ m^3}{kmol\ K} \times 423}$$

$$= 0.831\ \frac{kg}{m^3}$$



(a). An old filter from a discontinued process is to be utilized for a const. pressure filtration at 12.7 cm H_2O. The filter has 20 bags of ~~7430~~ 7432.24 cm^2 each surface area. Clean time of filter is 45 min. For given pr. filtration eqn which may be valid for old filter as

$$t = 674.82\ V_G^2$$

t = time, min

V_G = vol. of gas filtered per unit area, $\frac{m^3}{cm^2}$

Determine overall capacity of this filter under given condition

Sol: Given:

Area of one bag = 7432.24 cm^2

$$t = 674.82\ V_G^2$$

$$t_f + t_c = 674.82\ V_G^2$$

$$\text{Total area (20 bags)} = 20 \times 7432.24\ cm^2$$

$$= 148644.8\ cm^2$$

$$= 14.8644\ m^2$$

For optimum filtration, $t_f = t_c$

$$2t_c = \cancel{674.82}$$

$$45\ min = 674.82\ V_G^2$$

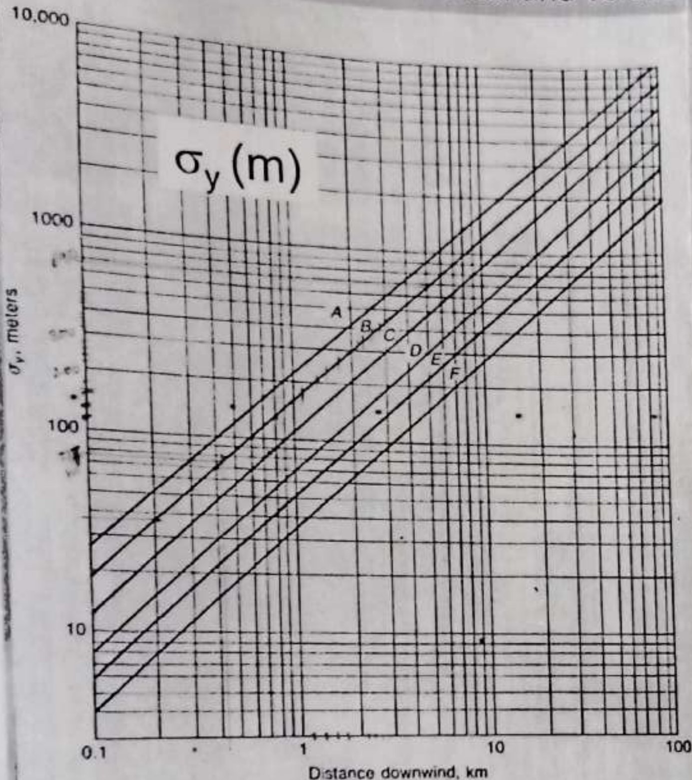
$$V_G = 0.2582\ \frac{m^3}{cm^2}$$

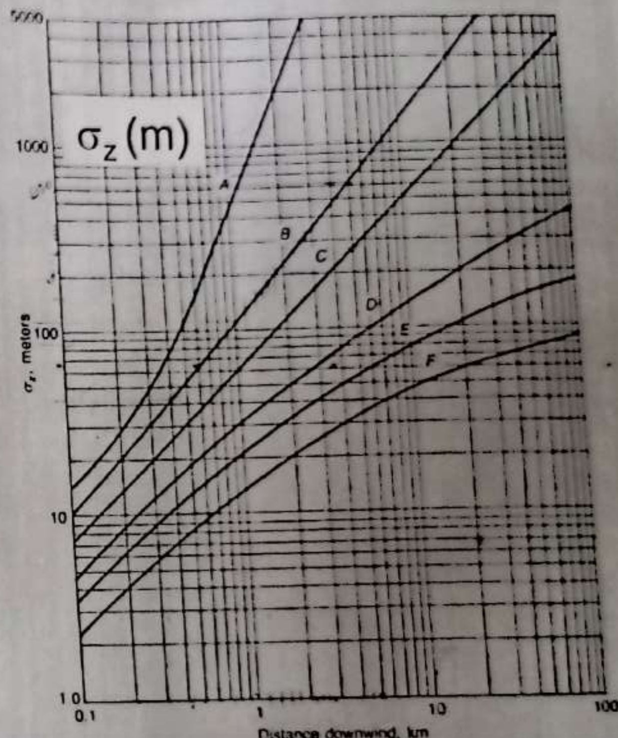
$$Q = \frac{V_G}{t_f + t_c} = \frac{0.2582 \ \frac{m^3}{cm^2}}{45 \text{ min}}$$

V_G for 20 bag $= 0.2582 \times$

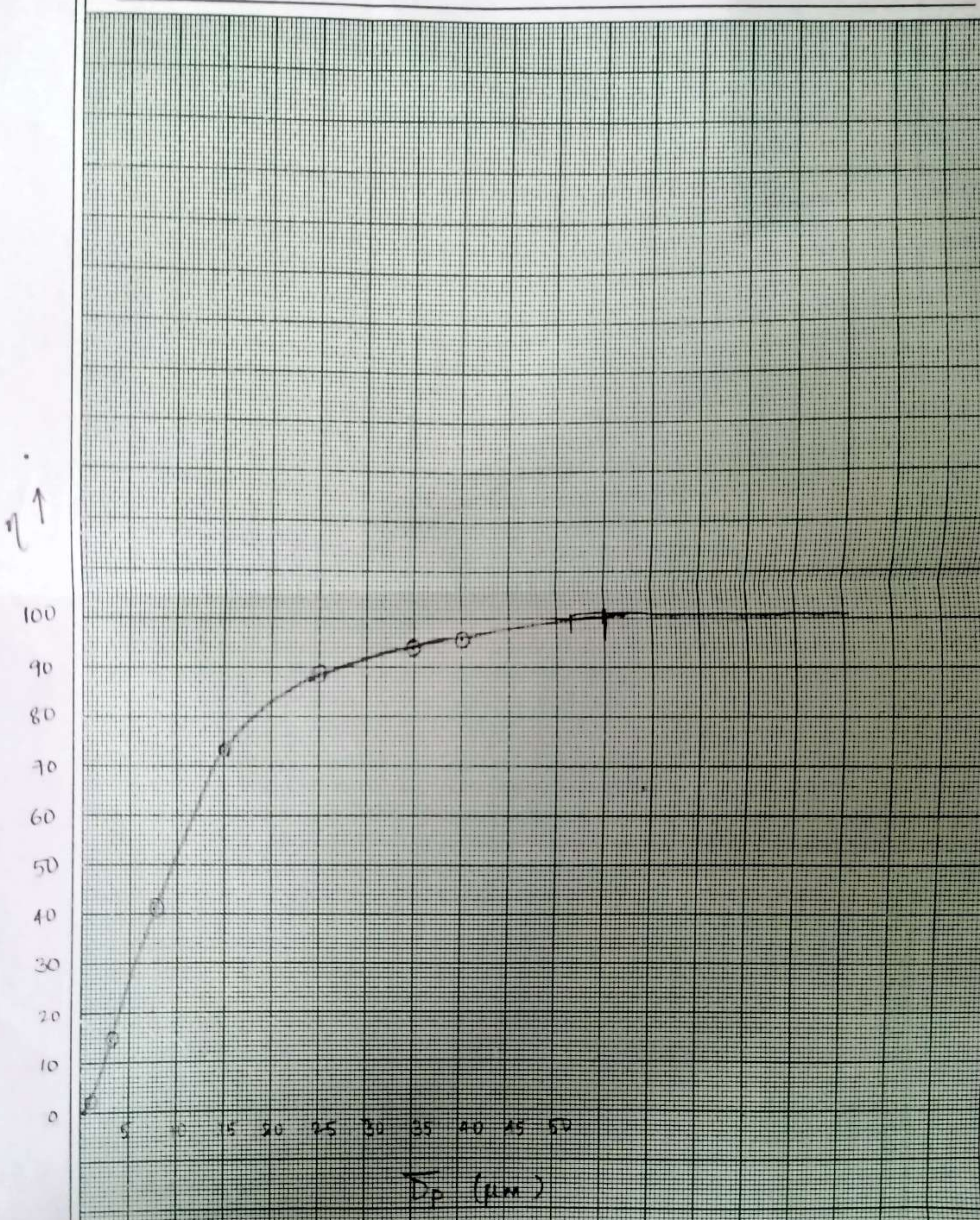
24CH60R24. HARIKA PILLA

Horizontal and vertical dispersion coefficients





Stability class	Definition	Stability class	Definition
A	very unstable	D	neutral
B	unstable	E	slightly stable
C	slightly unstable	F	stable



η ↑
100
90
80
70
60
50
40
30
20
10
0
5
10
15
20
25
30
35
40
45
50
$\overline{D_p}$ (μm)

30/9/24

→ 2°ry Treatment unit :

⇒ Alum (Aluminium sulfate)

Ferric sulfate

Ferric chloride

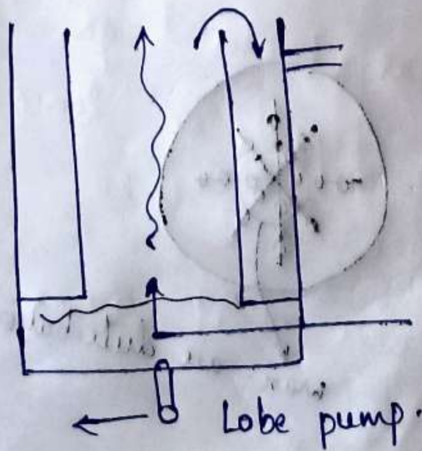
b) $Fe_2(SO_4)_3 + Ca(OH)_2$ $Al_2(SO_4)_3 \cdot 18H_2O + Ca(HCO_3)_2$

↓ ↓

$Fe(OH)_3 + CaSO_4 + H_2O$. $CaSO_4 \downarrow + CO_2 + H_2O + Al(OH)_3$

$FeCl_3 + Ca(HCO_3)_2 \longrightarrow Fe(OH)_3 + CaCl_2 + CO_2$

⇒ 1°ry treatment → TDS, TSS



Lobe pump.

Some times, due to malfunctioning of pump

↓

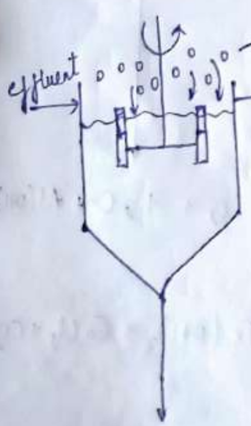
Overflow will be hazy due to suspended matter

→ Slurry (solids + water) → Rotating drum filter → Recycled water.

60 - 80% solid content

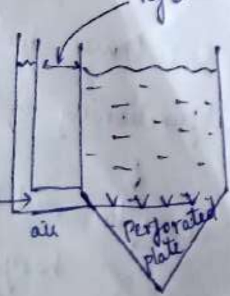
→ Secondary Treatment Methods :

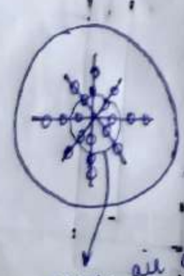
1. Aerated lagoon. → O_2 is supplied thru aeration.
2. Activated sludge.
3. Oxidation pond.



- water particles + air
- Henry's law const.

hydrostatic level (at start up) instead run air in empty tank





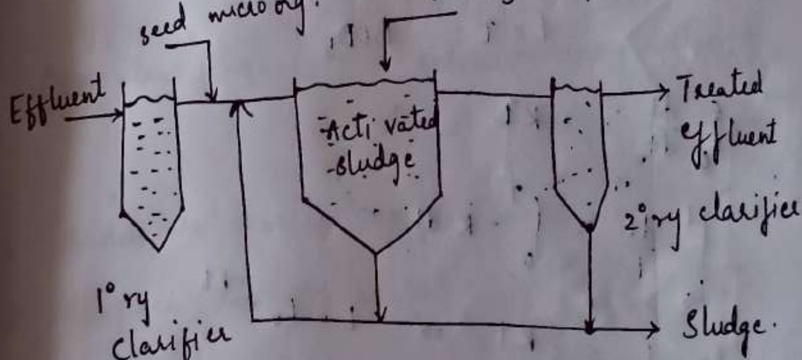
At start up, hydrostatic level is l

– run the air in empty tank.

⇒ In 1st tank, we can use an impeller type

 or multi impeller 

⇒ Activated Sludge :



Sludge from 2°ry clarifier contain micro org & recycled back → activated sludge.

10/9/24.

→ **Biological reactors** (Waste water treatment).

Kinetics: 1st order rxn rate

BOD_5^{20}

Rate of BOD removal $= \frac{dL}{dt} = -K_1 L$

$L = BOD$ $\quad t = 0$ $\quad$ Initial BOD

$\quad\quad\quad\quad t = \tau$ $\quad BOD_5$

$$\int_0 \frac{dL}{dt} = -KL$$

$$\int_{L_0}^{L} \frac{dL}{L} = \int_0^t -K\,dt \qquad L = L_0 e^{-kt}$$

$$\ln \frac{L}{L_0} = -Kt \Rightarrow$$

where L_0 = BOD at $t = 0$ → BOD (ultimate)

L = BOD at time $t = t$

$$\% \text{ BOD removal} = \frac{L_0 - L}{L_0} \times 100\%$$

$$BOD_5^{20} = L_0 (1 - e^{-kt})$$

$k = f(T)$ as bacterial growth activity depend on temp (T)

$$K(T) = K(20) \times \phi^{T-20}$$

ϕ = arhenius const (1.03 - 1.09)

For Mixed flow system:

Population equivalent (PE)

$$PE = \frac{\text{BOD load of any Industrial waste water from a particular Industry}}{\text{BOD } \frac{kg}{\text{person day}}}$$

Normally $0.054 - 0.08 \ \frac{kg}{\text{person day}}$.

Coagulant agent : Ferrous Alum instead of Potash Alum.

1. Industrial process effluent →
2. Surface run off water.

↓

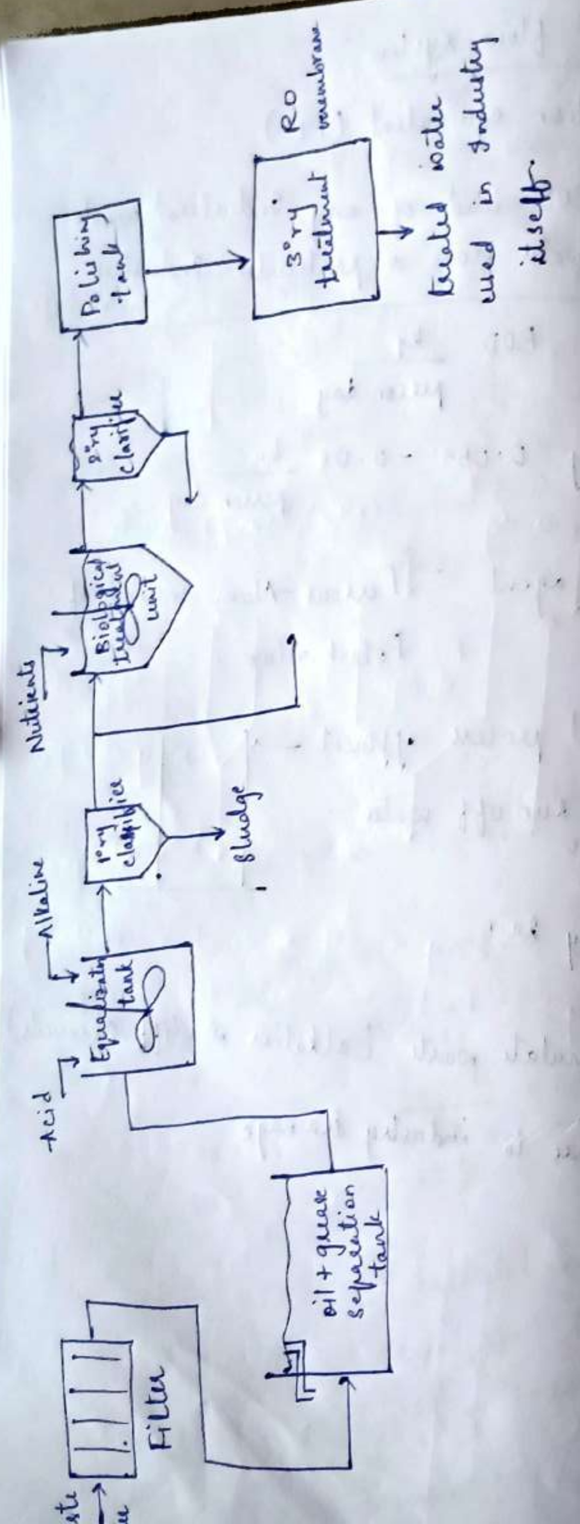
Heavy rain

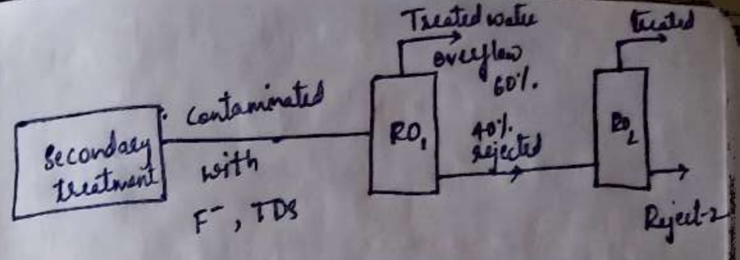
↓

Accumulate waste (alkalies or diff chemicals)

↓

Comes to industry drainage



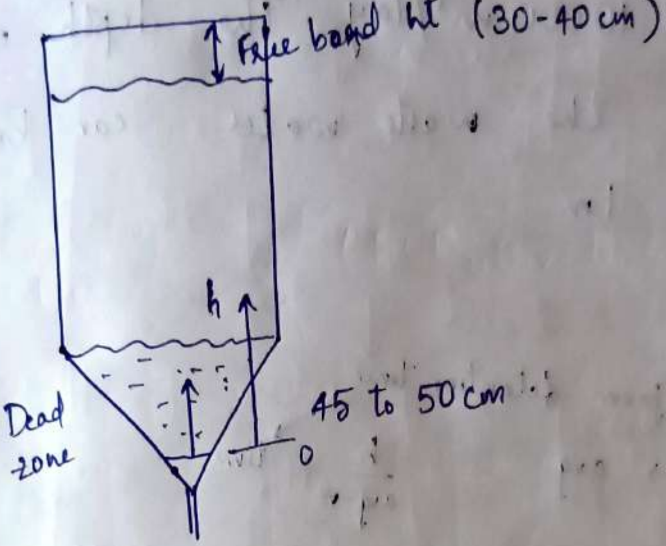


9/9/24

$$BOD_5^{20} = \frac{2}{3}(BOD_{ultimate})$$

14/10/24.

→ Settling Chamber:



→ Dilution factor = $\frac{10 - 100}{\text{order}}$

→ To sustain microbes   1st stage   2nd ...
100   50-100   1

→ During rainy season, the waste water becomes <u>septic</u> <u>condition</u>.

BOD

<u>Problem</u>: A grit chamber is designed to remove parti with a diameter of 0.2 mm and specific gravity of particles 2.65. The grit chamber serve as a $1^{o}ry$ clarifier and the settling velocity of the particles in the range of 0.016 - 0.024 m/s depending upon on their shape factor. A flow of

the waste water then the clarifier is maintained by maintaining a velocity of 0.3 m/s. Determine the retention time and dimensions of a clarifier for a max. capacity of waste water treated is 10 000 m³/day. The depth of clarifier upto which the waste water can be treated is 1m.

Area
dimension from detention time → time
settli vel → avg

$\frac{h}{avg \cdot ve} = $ time

Sol: Vol. flow rate (Q) = c/s area (A) × velocity (v)

$10000 \frac{m^3}{24 \times 3600 s} = A \times 0.3$

$A = \cancel{4.2592}\ 0.3858\ m^2$

ht × width = $\cancel{4.2592}\ 0.3858\ m^2$

Note: For settling chamber area = h × b.

$1 \times b = 4.2592\ m^2$

$b = \cancel{4.2592}\ 0.3858\ m$

$\simeq 0.4m$

Settling velocity = average velocity.

$u_{t_{avg}} = \frac{0.016 + 0.024}{2}$

$u_{t_{avg}} = 0.02\ m/s$.

⇒ detention time, $t = \frac{h}{avg \cdot vel (u_{t_{avg}})}$

$= \frac{1\ m}{0.02\ \frac{m}{s}}$

$= 50 s$.

⇒ Length of the settling chamber (clarifier)

L = detention time × velocity of waste water (v)

$= 50 \times 0.3$

$= 15\ m$.

⇒ Now considering dead zone and free board height
dead zone: assume 50 cm = 0.5 m
free board: assume 40cm = 0.4m.

∴ Total ht = 1 + 0.5 + 0.4
0.475 avg + 0.35 avg.

$= \cancel{1.9}\ m$.

$= 1.825m$

$\sim 1.8\ m$.

(2). Design a suitable clarifier chamber for a sewage treatment plant in a metropolitan corporation which gets 24000 lt/min of waste water in a dry weather. Assume the velocity of the sewage stream flow thru the clarifier at 0.2 m/s. The detention period of sludge is 2 min. The max. flow of the sewage may be assumed 3 times of dry weather waste water flow. Considering the generation of off gases and settling of the sludge matl, a min. free board ht. of 0.34 m and dead zone 0.45 m to be provided. Submit the design report of the clarifier.

Sol: Given : $Q = 24{,}000 \frac{lt}{min}$

$= 24000 \times \frac{10^{-3} m^3}{60\ s}$

$Q = 0.4 \frac{m^3}{s}$

vel. of sewage stream, $v = 0.2$ m/s.

detention time, $t = 2$ min $= 120$ s.

$Q_{max} = 3Q \Rightarrow Q_{max} = 1.2 \frac{m^3}{s}$.

$h_{free\ board} = 0.34$ m.

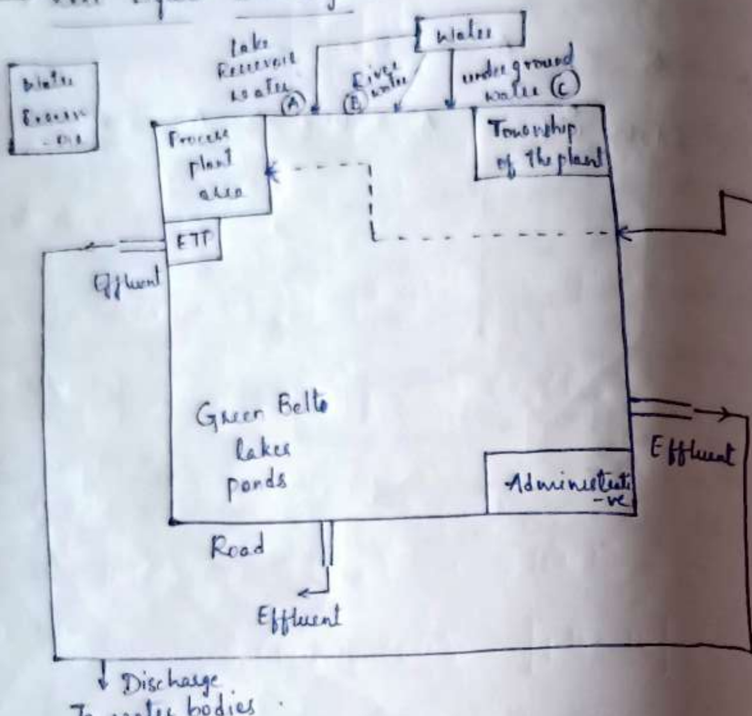
$h_{dead\ zone} = 0.45$ m.

$Q = A \times v$.

$0.4 = A \times 0.2 \Rightarrow A = 2\ m^2$

10/10/18

→ Zero Liquid Discharge (ZLD)



⇒ In ZLD, there will be no discharge from the plant.

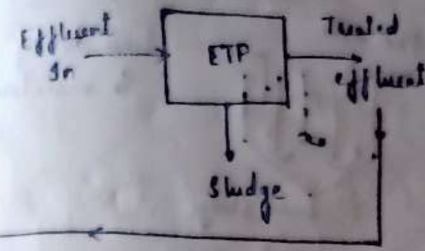
⇒ Water Balance:

A + B + C (volume)

↓ losses (due to evap, leakages)

↓ water in product

↓ Effluent



⇒ By doing a water balance, we can show the whether a plant is ZLD or not.

→ ZLD is not zero discharge, it is zero liq discharge (∵ sludge is discharged)

→ Take any Chemical Process plant (Eg: Cement, Soap, Detergent) Chemical Tech by (Kirk Othman Dryden) → flowsheet, how much water consumption (including township, admin)

Design a problem how the plant is maintaining ZLD by making complete water balance.

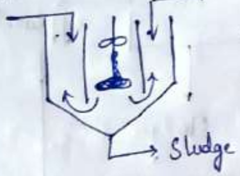
★ water / day

★ Online flow meters → flow rate, Totalizers.

→ Fluoride permissible limit : 1.5 - 2 mg/L → for drinking water

→ Clarifier - I : pH should be 7

Effluent from Phos. acid
pH : 3.5



★ Removing P & F at same

→ This rxn mech of phosphate and fluoride removal.

i) $3Ca^{+2} + 2(PO_4)^{3-} \longrightarrow Ca_3(PO_4)_2$ $\boxed{pH = 7}$ ↓ phosphate removal

ii) $10Ca^{2+} + 6(PO_4)^{3-} + 2(OH)^{-} \longrightarrow$

$Ca_3(PO_4)_6(OH)_2$ $\boxed{pH = 10}$ → fluoride removal.

iii) $Ca(OH)_2 + 2HF \longrightarrow CaF_2\downarrow + 2H_2O$.

iv) $Ca(PO_4)_6 + 2CaF \longrightarrow Ca(PO_4)_6 CaF_2\downarrow$

→ Clarifier-II O/L. water have pH = 10, to correct it we do H_2SO_4 dosing in neutralization tank.

→ Initial DO content 5-6

→ BOD (Temp . time)

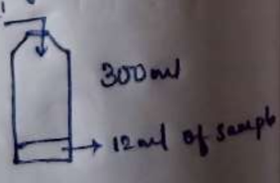
Problem 1

A waste water sample collected from refinery plant is used for BOD measured by a series of dilution in a 300 ml std BOD bottle. The dilution range, initial DO and final DO values are given in following table. Calculate avg BOD of refinery waste water

BOD Bottle no	ml of refinery waste water	Initial DO	Final DO
1	3	7.95	5.2
2	6	7.95	3.85
3	9	7.90	2.40
4	12	7.85	1.35

Sol:

BOD : mg of O_2 consumed by micro organisms in _time at_temp. DW



i) Dilution factor = $\frac{300}{\text{ml of sample}} = \frac{300}{3} = 100$.

BOD = D.F × O_2 consumed

= 100 × 2.75

= 207.5 275

O_2 consumed (Initial DO - Final DO)	Dilution factor	BOD
2.75	100	207.5 275
4.1	50	205
5.5	33.33	183.315
6.5	25	162.5

Avg = $\frac{\Sigma BOD}{4}$

= ~~128.953~~ 206.45

(2). Determine the BOD_5 from a waste water collected from integrated steel plant and samples were kept in BOD incubator at 20°C for 5 days in 500ml std BOD bottles. The data collected are:

BOD Bottle no.	ml of waste water	Initial DO	Final DO (mg/lt)
1	10	9.8	6.9
2	50	8.6	4.5
3	75	8.2	1.2
4	125	8.1	0

Based on above data, cal BOD_5^{20} (mg/lt)

Sol:

O_2 consumed	Dilution factor	BOD_5^{20}
2.9	50	145
4.1	10	41
7	6.66	46.62
8.1	4	– dont 32.4

(3). The waste water ETP of a fertilizer plant treat the waste water containing BOD_5^{20} of 400 mg/lt Aerated lagoon is used to treat the waste water and 'k' values at 20°C 0.023/day. Calculate the BOD_{10} at 35°C. Find out the efficiency of the aerated lagoon. Also calculate ultimate BOD.

Sol: $L = L_0 e^{-kt}$ $\Rightarrow \ln L_{20} = \ln L_0 - k_{20} t_5$ — ①

At 20°C & 5 days $k_{35} = 1.047$/day

$$\frac{400}{L_{35}} = \frac{L_0 e^{-0.023 \times 5}}{L_0 e}$$

$$400 = L_0$$

$$\ln L_{35} = \ln L_0 - k_{35} t_{10} \quad \text{— ②}$$

① - ②:

$$\ln\left(\frac{L_{20}}{L_{35}}\right) = k_{35} t_{10} - k_{20} t_5$$

$$\ln\left(\frac{400}{L_{35}}\right) = \overset{=1.047}{k_{35}} \times 10 - 0.023 \times 5$$

$$L_{35°C} = 0.0358 \text{ mg/lt}$$

$$L_{35} = L_0 e^{-1.047 \times 10}$$

$$L_0 = 1263.277$$

$$k_{35^\circ} = k(20) \times \phi^{(T-20)}$$

$$= 0.23 \times (1.047)^{35-20}$$

$$= 0.458$$

$$L_{35^\circ} = L_0 \times e^{-k_{35} t}$$

$$= 1263.277 \times e^{-0.458 \times 10}$$

$$=$$

Sol:

$$BOD_5^{20} = 400 \text{ mg/lt}$$

$$L_0 - L = 400 \text{ mg/lt}$$

$$k_{20} = 0.23/\text{day}$$

$$BOD_{10}^{35} = ?$$

$$\Rightarrow BOD_5^{20} = L_0 (1 - e^{-k_{20} t})$$

$$400 = L_0 [1 - e^{-0.23 \times 5}]$$

$$\boxed{L_0 = 585.34 \text{ mg/lt}}$$

$$\Rightarrow k_{35} = k(20) \times \phi^{(T-20)}$$

$$= 0.23 \times (1.047)^{35-20}$$

$$= 0.458$$

$$BOD_{10}^{35} = L_0 (1 - e^{-k_{35} t})$$

$$= 585.34 \times [1 - e^{-0.458 \times 10}]$$

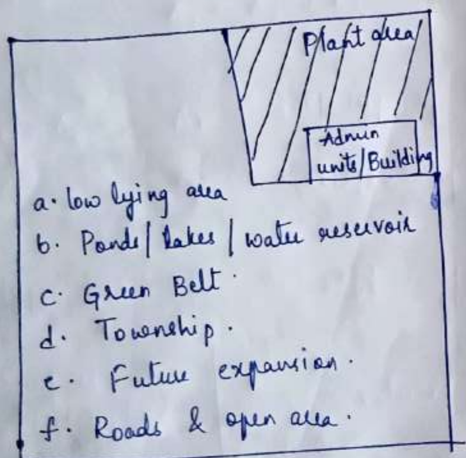
$$= 579.34$$

21/10/24.

→ Surface Run-off waste water management

1. RM handling.
2. Rxns / Separations.
3. Pdt packaging & Dispatch.
4. Storage of Hazardous matl / Solid wastes.

} occurs in plant area

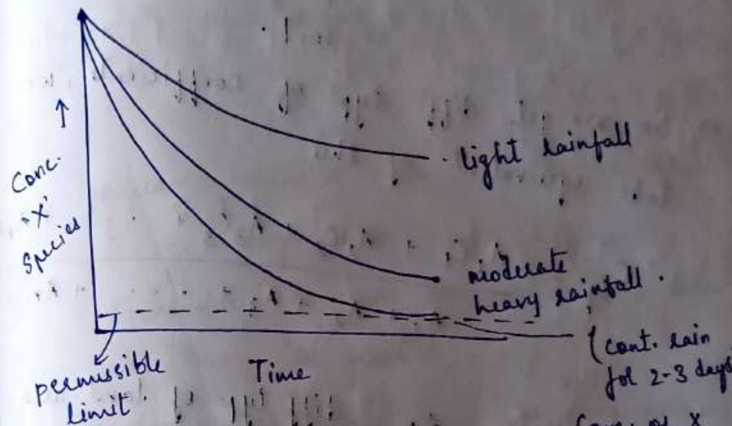


⇒ During Heavy rains, chemicals will present in run off water.

t = 0

ZLD

Surface run-off.



→ overflows

★ Do not mix ETP & surface runoff treatment should be done

⇒ Store the water, solids will settle down. Sometimes, it can be used for plant purposes depending on the conc.

→ To calculate:

① Total surface area of the plant premises (excluding admin & a to f): (A)
GIS area = shaded area.

② Surface run-off coefficient (C)

- Diff type of soil conditions (mud, porous, Sandy)
- diff type of conditions of surface

Eg: roads - concrete
- pavement
- soil.

⇒ So we get diff. type of coefficients, we take equivalent of this

$$C_{Eq} = \frac{A_1C_1 + A_2C_2 + A_3C_3 + \dots + A_nC_n}{A_1 + A_2 + A_3 + \dots + A_n}$$

$A_1, A_2, A_3 \dots A_n$ = diff type of land area.

$C_1, C_2 \dots C_n$ = corresponding coeff.

⇒ Land Types & Surface run-off coefficient.

Surface Description	C- values
Sandy soil	0.05 - 0.10
Heavy soil	0.13 to 0.17
Concrete road	0.70 - 0.95
Roof	0.75 - 0.95
Forest area	0.05 - 0.25
Buildings	0.82 - 0.88

③. Rainfall Intensity, I (mm/day, mm/hr)

- Collect data of this from IMD (Indian Meteorological dept).

④. Calculate peak runoff (Q)

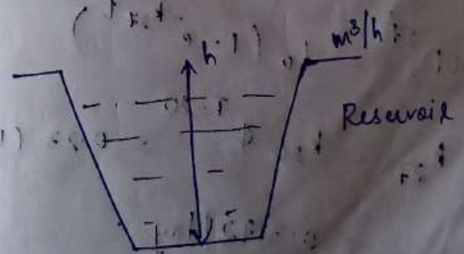
$$Q = C_{Eq} \times I \times A \quad m^3/day, \; m^3/hr$$

- average intensity data need to be taken.
- I → avg. intensity for a time.
- Generally 5 years rainfall data is taken (or) 20 years.
- In a particular, when the max rainfall occurred.
- In the 5 (or 20) years, to see when the highest rainfall happened.

★★ Average intensity of 5 years rainfall (if not 20 years)

From this we get Q ∴ $Q = C_{Eq} \times I \times A$ (A → area of that plant)

Then calculate storage area.



Problem :

The ultimate BOD of a waste water is estimated 87% of total COD. The COD of waste water is 300 mg/lt considering the first order BOD rate const $k = 0.23/\text{day}$ and coefficient $\theta = 1.047$. Calculate the BOD_3^{27} for this waste water.

ii) In 7-days time, what % BOD will be removed.

Sol: Ultimate BOD, $L_0 = 0.87\ COD$

$L_0 = 0.87 \times 300 = 261$ mg/lt.

$L_0 \quad L = 2$

$BOD_5^{20} = L_0(1 - e^{-kt})$

$261 = L_0(1 - e^{-0.23 \times 5})$

$L_0 = 381.934$

$L_0 = 261$ mg/lt

$BOD_3^{27} = L_0(1 - e^{-k_{27} t})$

$k_{27} = k_{20}\,\theta^{T-20} = 0.23\,(1.047)^{27-20}$

$= 0.3172/\text{day}$

22/10/24.

Monsoon Peak Run-off:

Year

June July Aug Sept Oct.

8/7/15	200
15/9	150
28/7	130
	105

Date July 2015 Aug 15.

1
2
3
4

2016   lly 2017 2018 2019.

20/8/2016	500
5/10	200
10/9	180
20/7	50.

Peak Average:

2015 2016 2017 2018 2019.

$$\frac{R_1 + R_2 + R_3 + R_4}{4}$$

2020 2021 2022 2023 2024.

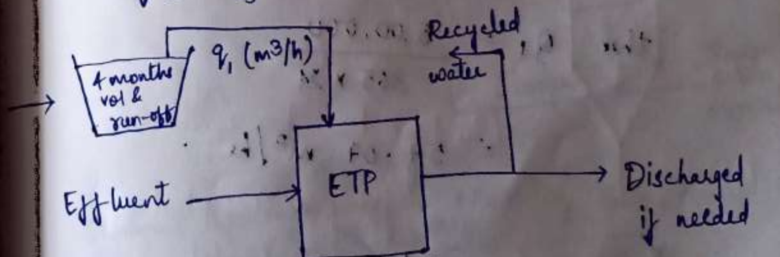
Take lower value +10% extra

If the values are ↑ ↓, then

$$\frac{R_1' + R_2' + R_3' + R_4' + \dots R_{10}'}{10.}$$

$\Rightarrow Q = C_{eq} \times I \times A$ $\frac{m^3}{day}$, $\frac{m^3}{months} \times 4$ months

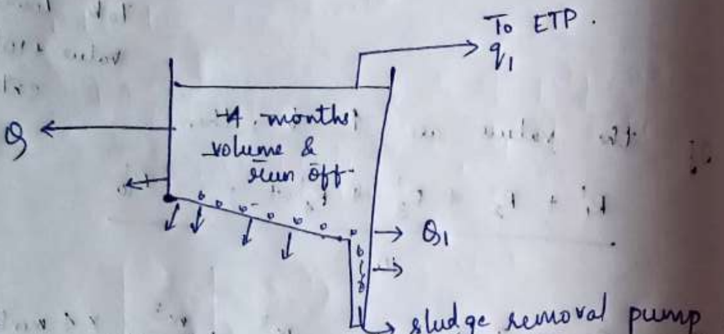
$V = Q \times 4$ months



⇓

This is designed for 20% extra

→ Sometimes the runoff needs 72 hrs to settle down and the sediments from storage should be removed or else the pollutants may percolate into the soil, so the pond surface should be lined (like HDPE sheets)



→ If pond it is of capacity 5,00,000 m³

then $Q_1 = \frac{5,00,000}{365 \times 24}$

$= 57.07$ m³/hr

$Q = 2500$ m³/day

$Q = 104$ m³/hr

$Q_{reused} = 104 - 57 = 61$ m³/hr

(2). Increase the capacity of the ETP : to 250 m³/hr

$ETP_{new} = 250 + 58$

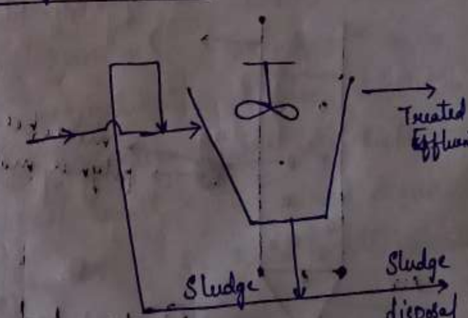
$= 308$ m³/hr

Additional cost :

(1). Reuse

→ Choose the Industry, find various runoff water, design, calculate capacity of reservoir capacity.

→ Activated Sludge Process



$$\text{Sludge loading rate} = \frac{\text{Mass of } BOD_5/\text{day}}{\text{Mass of MLSS}}$$

MLSS → Mixed liquor suspended solids.

→ From activated sludge, sludge or mud.
It is sun-dried and can be used as fertilizer

Sometimes it contains hazardous matt, mix it with product (non-consumable)

↓

like Insecticides.

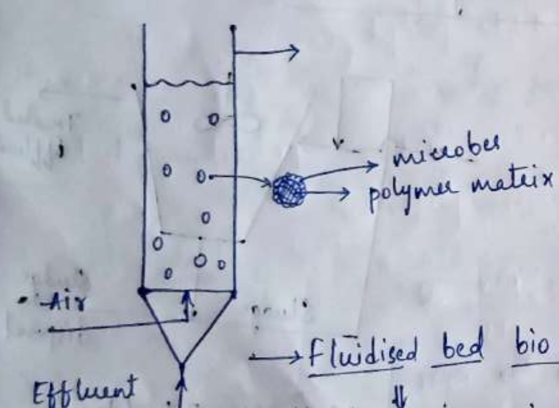
⇒ Detention time req.

⟶ If effluent contains pharmaceutical waste, microplastics

we use ⇓

i) Fluidised bed bioreactor

2) Packed bed
Fixed bed is made of polymeric balls whose density > density of water
1.05 - 1.10.

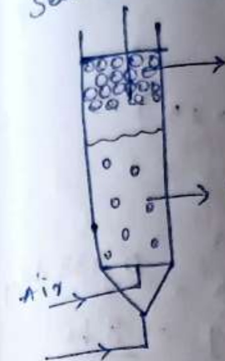


⟶ Fluidised bed bio reactor

⇓

used for micro-plastics.
Pesticides
CN^-
Carcinogenic organics
BTX.

Semi - Fluidised.



Packed ⇒ ΔP is more
removal of pollutants is also more.

⇒ Series of Parallel bioreactors can be used → to min Flow rate

An activated sludge plant is used for treatment of petrochemical waste water at a daily flow rate 3000 m^3. The BOD_5^{20} of is 200 mg/lt. In the activated sludge plant two aeration tanks 4m depth × equal volume of 5m width, 25m length. The mixed liquor suspended solids conc. is 2100 mg/lt. Calculate

i) Detention time
ii) Volumetric organic loading rate
iii) Sludge loading ratio

Sol: Given $Q = 3000\ m^3/day$

$BOD_5^{20} = 200\ mg/lt$.

$MLSS = 2100\ mg/lt$.

$\frac{V_1 + V_2}{u}$.

Dimensions of the tank : $\overset{H}{4} \times \overset{W}{5} \times \overset{L}{25}$ m.

(i) 2 tanks = 2 (4 × 5 × 25)

$(V_1 + V_2) = 1000 \ m^3$.

Detention time $\left(\frac{V_1+V_2}{Q}\right) = \frac{1000 \ m^3}{3000 \ \frac{m^3}{day}} = 0.333$ day

$= \underline{8 \ hr}$

ii) Volumetric organic loading rate

$= \frac{BOD_5^{200} \text{ loading rate}}{\text{Total volume}}$

$= \frac{\text{kg of BOD}}{}$

BOD_5^{200} loading $= \frac{BOD_5^{20} \text{ entering}}{\text{Total vol of aeration tank}}$

$= \frac{200 \ \frac{mg}{lt} \times 3000 \ \frac{m^3}{day} \times 1000 \ lt}{1000 \ m^3}$

$= 600 \ \frac{g}{day}$ $\quad 600 \frac{g}{m^3 day}$

$= 0.6 \ \frac{kg}{m^3 day}$

iii) Sludge loading ratio = $\frac{\text{Mass of } BOD_{5 \ Load}^{20} / day}{\text{Mass of MLSS}}$

MLSS $= \frac{2100 \ \frac{mg}{lt} \times 3000 \ \frac{m^3}{day} \times 1000 \ lt}{}$

Sludge loading ratio $= \frac{0.6 \ \frac{kg}{day}}{6.3 \ \frac{kg}{day}}$ $\quad \frac{600 \ \frac{kg}{day}}{6300 \ \frac{kg}{day}}$.

$= \underline{0.095}$.

Problem : An industrial waste water from an diary industry discharge at the rate of 1 lakh gallon/day to the ETP for its treatment. The BOD of the effluent is 20°C & 5 day 220 $\frac{mg}{lt}$. After the treatment, the treated effluent from ~~unit~~ ETP is discharged at BOD 20 $\frac{mg}{lt}$. Find out

i) kg of BOD entering the ETP

ii) % removal of BOD in the ETP.

iii) BOD discharge rate in kg/day from ETP

Sol: For the ETP : MGD million gallons per day.

$Q = 1 \times 10^5 \times 3.785 \ \frac{lt}{day} = 378.5 \ \frac{m^3}{day}$

$BOD_5^{20} = 220 \frac{mg}{lt}$

$L_0 - L_t = 220$

$\frac{L_0 - 20}{\cancel{20 - L_0}} = 220 \Rightarrow L_0 = 240 \frac{mg}{lt}$.

$\Rightarrow$ BOD entering $= \overset{220}{240} \frac{mg}{lt} \times \frac{3.785 \times 10^5 \; lt}{3.78541 \; day}$

$\underline{88.279 kg.} = \cancel{90.84 kg} \cdot \frac{220}{1000 \times 1000} \times 3.785 \times 10^5$

ii) % BOD removal : $\frac{L_0 - L_t}{L_0} \times 100$

$= \frac{220 - 20}{220} \times 100$

$= \cancel{91.66\%} \quad \underline{90.9\%}$

iii) The BOD discharge rate in $\frac{kg}{day}$

$= 20 \frac{mg}{lt} \times 3.78541 \times 10^5 \frac{lt}{day}$

$= \underline{7.54 \; kg}$

→ **ESP** :

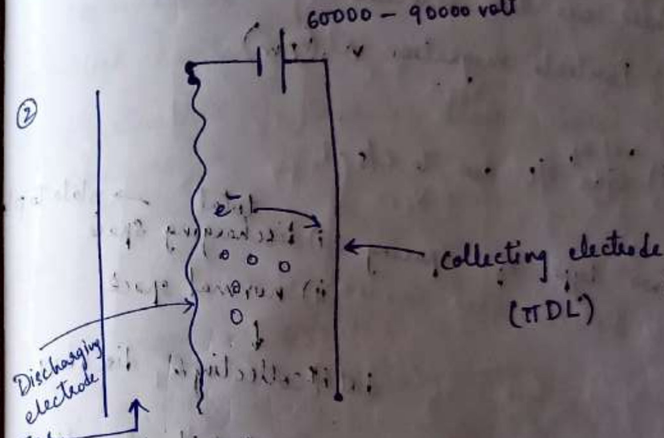
⇒ Particle size dia = 0.1 μm - 20 μm.

⇒ Two types

1) Plate to Plate type

2) wire

(2)

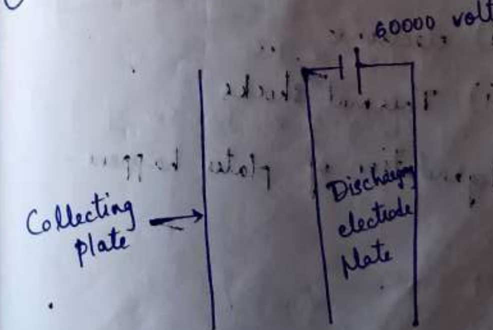


Two mechanism :

1) bombardment mechanism

2) diffusional mechanism

(1) Plate to plate type



⇒ Fossil pollutant particle collected by ESP

⇒ Properties :

i) Dielectric constant of particles

⇒ There are two velocities :

i) Particle migration vel, (v_{pm})

ii) vel of Gas r/t due to c/s.

⇒ Two type of spacing -: i) discharging space total → plate to plate

ii) normal space ↓ dist b/t collecting & discharg

⇒ If dist b/t discharging electrode & collecting electrode plate, e^- → collecting formation ; particles are not removed

min = 30 cm - 40 cm is provided.

⇒ Shocks : i) electronic

ii) Thermal shocks

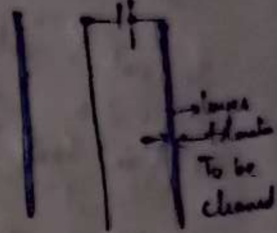
↓

Thermal degradation of plates happens.

→ Cleaning methods :

Due to layer formation Overall resistivity inc, eff dec

typical η - 99.95 %.



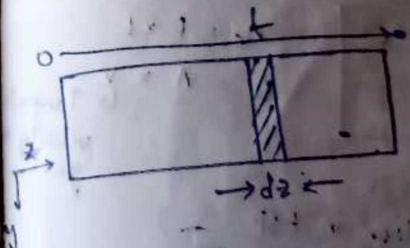
⇒ Design of it is sophisticated.

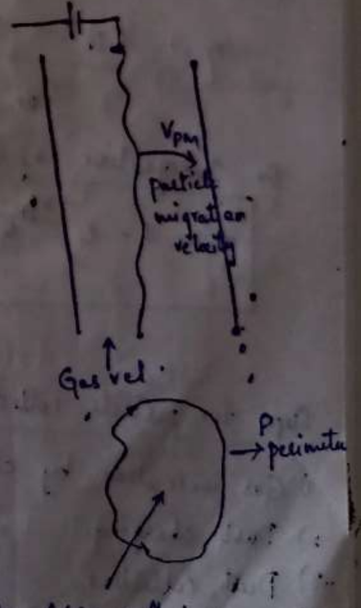
⇒ High capital cost

⇒ Fluctuation of flowrate, temp causes drastic changes in ESP.

10/24

→ Efficiency of ESP :





C/s . Area = A

Mass balance over control volume :

In = out + dust collected

In - out = collected dust

$$AV(\bar{C}_{in} - C_{out}) = AV \cdot \frac{\partial C}{\partial z} = V_{PM} \times P \cdot dz \cdot C$$

$$AV \frac{\partial C}{\partial z} = V_{PM} \, P \cdot C$$

$$AV \int_{C_0 = C_{in}}^{C_L = C_{out}} = V_{PM} \int_0^L dz$$

Mass balance over control volume .

$$\eta = \frac{C_{in} - C_{out}}{C_{in}} = \frac{C_0 - C_L}{C_0} \quad \text{— A}$$

On Integration of (A) :

$$\boxed{\eta = 1 - e^{-\frac{V_{PM} \cdot A_C}{Q}}}$$

$A_C = P \times L$

$Q = A \times V$ → Tangential velocity of gas

Steps for particle collection in ESP :

1) Gas ionization by changing mechanism of particles
2) Dust charging
3) Dust collection
4) Dust build-up
5) Dust removal

$A_C = P \cdot L$

$Q = A \times V$

Flue gas : $D_p \sim 0.1 \, \mu m$ to $40 \, \mu m$.

$V_{PM} \approx 0.14$ to 0.18 m/s.

D_P	$\bar{D}_P$
0.1 - 1	0.55
1 - 10	5.5
10 - 20	15
20 - 30	25
30 - 40	

$$V_{PM} = \frac{q_{Lt} \cdot EC}{3\pi \mu d_p}$$

q_{Lt} = at what $\frac{\text{voltage}}{\text{dist}}$ = Lt electric discharge

C = Cunningham correction factor

μ = viscosity of gas

d_p = particle dia in μm

E = Elec. field

$\Rightarrow q_{Lt} \rightarrow q_{Lt}|_b + q_{Lt}|_{diffusion}$

Bombardment mech. ; diffusion mechanism

$\Rightarrow (q_{Lt})_b = n \cdot e = f(E, r_p)$

$= 0.49 \times 10^{-9} \, r_p^2 \, E$

n = no. of electron charges.

e = electron charge = 1.6×10^{-19} C

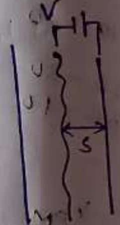
$E = AV$ ∴ electric field intensity, $\frac{V}{m}$

$\epsilon = 2.5$ (di-electric constant)

For other particles

$$q_{Lt}\Big|_{b} = q_{Lt}\big|_{b \text{ at } \epsilon = 2.5} \left[\frac{D_{\epsilon=\epsilon}}{D_{\epsilon=2.5}}\right]$$

$$\epsilon = 2.5 \left[\frac{D_{\epsilon=\epsilon}}{D_{\epsilon=2.5}}\right]$$



$$D = 1 + \frac{2(\epsilon - 1)}{\epsilon + 2}$$

$$E = \frac{V}{S}$$

$$\frac{V_{PM_1}}{V_{PM_2}} = \frac{E_1}{E_2} = \frac{V_1}{S_1} \times \frac{S_2}{V_2}$$

$$\frac{V_{PM_1}}{V_{PM_2}} = f(S, V)$$

⇒ Cal. A_c = collecting surface are = ht × wid × 2

ht ≯ 4 – 5 m
width ltd to 6m } But depends on cap of gas

② V_{PM} = f (v, type of particles, etc)

③ Q = given

④ find ϵ = di-elec const.
↓
whether

→ $\bar{D}_p$
↳ D → to change it
↳ changed D
↓
particle gets charged easily.

Eg: Flue gas:

SO_2
PM → fly ash $D_p = 0.1 \mu m$
NO_x
CO
O_2
N_2
unburnt C
H_2O (v)
CO_2

$H_2O(v) + SO_3 + \underset{\text{dose}}{NH_3} \rightarrow$

$(NH_4)_2SO_3$ (or)
$(NH_4)_2SO_4$ } hygroscopic in nature

Flue gas conding to ↑ 'D'.

These – adhesive nature of particles
attached to other
particle dia ↑

⇒ If A_c = 500 cm²

To ↑ η : ~~change D~~
change q_{Lt} (change 's')
iff it is < 30cm
V_{PM} directly depends on 's'

plate - plate spacing :

normal spacing :

29/10/24.

①. A parallel horizontal ESP consists of plate to plate plates of 5m ht and 6m length with 30cm plate spacing having a collection eff. of 94.4%. The flue gas enters through the ESP @ 1,08,000 m^3/hr. Inlet dust loading is 10 g/m^3. Calculate

a) bulk velocity of the gas

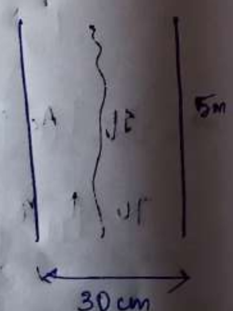
b) O/L conc. of the dust particles

c) dust particle migration velocity

d) Find out efficiency if the flowrate is ↑ed to 2×10^5 m^3/hr.

e) Find out eff. if the spacing is 20 cm.

Sol: Given : plate - to - plate



$A = 5 \times 0.3 = 1.5 \, m$

c/s area $= h \times W$

$= 5 \times .25$

a) vel. of gas $= \dfrac{Q}{A}$

$= \dfrac{108000}{5 \times 0.3 \times 3600} \dfrac{m^3}{s}$

$= 20 \dfrac{m}{s}$

b) O/L dust conc :

$C_{in} = 1,08,000 \times 10 = 108 \times 10^4$

$\eta = \dfrac{C_{in} - C_{out}}{C_{in}} \times 100$

$0.944 = \dfrac{C_{in} - C_{out}}{C_{in}} = \dfrac{10000 - C_o}{10000}$

$C_{out} = 60480 \, g/m^3$ 560 mg/m^3

c) $\eta = 1 - e^{-\frac{V_{PM} \cdot A_c}{Q}}$

$A_C = 2(5 \times 6) = 60 \, m^2$

$0.944 = 1 - e^{-\frac{V_{PM} \times 60 \times 3600}{108000}}$

$V_{PM} = 1.44 \, m/s$

d) If $Q = 2 \times 10^5 \, m^3/hr$

$\eta = 1 - e^{-\frac{1.44 \times 60 \times 3600}{2 \times 10^5}}$

$= 78.88 \%$

e) If spacing is $s = 20$ cm.

$$\frac{V_{PM_1}}{V_{PM_2}} = \frac{S_2}{S_1} \cancel{\times \frac{V_1}{V_2}} \Rightarrow \frac{20}{30} = \frac{1.44}{V_{PM_2}}$$

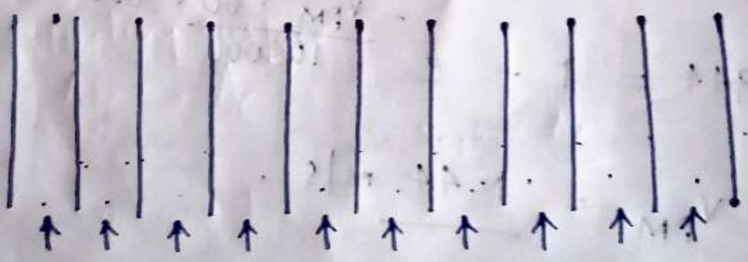
$$V_{PM_2} = \underline{2.16 \text{ m/s}}.$$

$$\eta = 1 - e^{-\frac{2.16 \times 60 \times 3600}{108000}}$$

$$= 0.986 \simeq \underline{98.6\%}.$$

(f) If instead of 2 parallel plates 11 no. parallel plates are used, find particle migration velocity and efficiency for 108000 ~~2×10^5~~ m^3/hr

Sol: $V_{PM} =$ 0.263



Spacing (not used) = ~~100~~ 30 ~~300 cm~~ =

For 11 plates, c/s area =

$$A_c \Rightarrow \frac{V_{PM_1}}{V_{PM_2}} = \frac{V_1}{V_2} \times \frac{S_2}{S_1}$$

(2). As recently hired ~~foreign~~ engineer for an eqpt manufacturing company have assigned job of the process design of ESP, to treat ~~10^5~~ ~~122000~~ ~~100032~~ 132000 m^3/hr of gas containing gypsum particles from a gypsum plant. The gypsum I/L loading is 77.6 g/m^3 and outlet loading 1140 mg/m^3. Submit the design report of ESP.

Sol: Dim.
S.A
plates
Spacing.
η

Given: $Q = 132000 \ \frac{m^3}{hr}$

a) $$\eta = \frac{77600 - 1140}{77600} = 0.985 \simeq 98.5$$

b) Collecting surface Area = A_C.

$$\eta = 1 - e^{-\frac{V_{PM} \times A_C}{Q}}$$

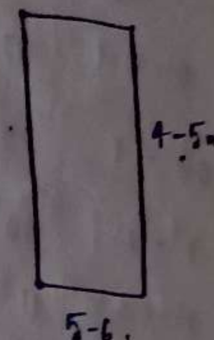
$$0.985 = 1 - e^{-\frac{0.16 \times A_C}{132000}}$$

900 m^2

$$A_C = 962.43 \ m^2.$$

No. of plates to be taken = ?

Generally spacing = 0.3 m.



$$962.43 = n \times (4 \times 5)$$

$$n \approx 48$$

Area = $0.3 \times 4 \times n$.

$\eta = 0.98$

(3) A stack gas flows thru ESP is 12 m^3/s. The plate area is 250 m^2 and V_{PM} has been found to be $2.8 \times 10^5 \ D_p$. Draw a particle size eff curve for the particle ranging from 0.1 to 10 μm. The plate spacing is 25cm. If the size distribution of the particles are given as per table below:

a) Cal η.

b) If the plate spacing reduced to 20cm calculate η

Size Range (μm)	wt (g)	Avg. $\overline{D}_p$
0 - 0.1	12	
0.1 - 1	25	
1 - 2	30	
2 - 3	11	
3 - 4	13	
4 - 7	5	
7 - 10	4	

- Cal v_{P_m}
- η_i
- $25 \rightarrow 20$

$$\frac{v_{PM_1}}{v_{PM_2}} = \frac{y_1}{y_2}\,\frac{S_2}{S_1}$$

$v_{PM\ new\ i}$

again η

③. A wire in tube type ESP is having collecting electrode surface area of $300 m^2$ to sep. alkaline dust particles from a cement manufacturing plant. The flue gas flow thru ESP $7200 \frac{m^3}{hr}$ at temp 95°C which passes thru ESP where 56000 Volts is maintained b/t the discharge and the collecting electrode which are 12.5cm apart. Calculate the particle migration velocity and efficiency of separation for 1μm particle. The density of particle is 2500 kg/m^3 & the viscosity of gas is 0.0225 poise. Assume diffusional mechanism to charge the particles predominantly in the ESP. The Cunningham factor

$$\frac{1 + 0.172}{D_p}$$

Sol: ① $q_{Lt} = q_{diff}$.

② η

③. $E = \frac{V}{S}$

④.

An ESP must be designed to process $300 \frac{m^3}{min}$ of a stack gas. The particle migration velocity which passes through the ESP can be calculated from the formula $V_{PM} = 1.5 \times 10^5 D_p$. Calculate the plate area req. to remove particles of diameter ~~0.0~~ 0.7 μm so that 95% removal efficiency is achieved by ESP. If the particle size ranges in b/t 0.01μm - 0.05μm in the stack gas a) draw the particle migration velocity ~~parti~~ profile along with their individual η b) if 95% of particles is greater than 0.1 μm what will be the overall collection eff.

c) If the flowrate of gas suddenly ↑es 7.5 m^3/s, what will be the % change in the eff

Sol: ①.

②. $\frac{0.1 \mu m \rightarrow V_{PM}}{eff}$.

③. $Q \rightarrow 7.5$

(5). A cylindrical ESP of 0.3 m dia is used for sep fly ash from a furnace gas stream. If The vol. flow rate of the gas is 250000 m^3/h a) what will be the length of the precipitator for obtaining a collection eff 99.9% for ℓ

b) what % change in electrod collectiond area is req. to ↑ the collection eff. from 99.5% to 99.95%.

Sol: $v_{PM} = 0.14 - 0.18$

a) $D = 0.3$ m
30 cm

S = 15 cm

ℓ =
multiple no.

Wet Scrubber:

→ ESP : flue gas, ~~gaseous~~

→ others before : PM.

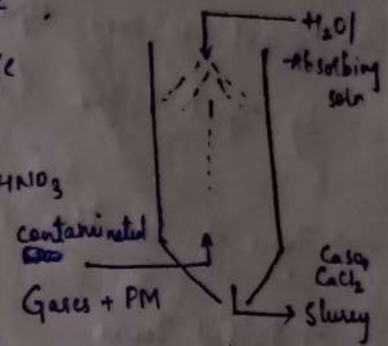
→ But some times in the process, flue gases like SO_2, NH_3, HF → wet Scrubber.

SO_2 : Lime / caustic

HCl : Lime / caustic

NH_3 : waste acid
H_2SO_4 / HNO_3

If conc is low : water



⇒ As T↑, solubility of gas ↓ (Henry's law)

⇒ Slurry : PM + $CaCl_2$ + $CaSO_4$.

⇒ If there is any PM present in feed gas for scrubber; removal of PM is necessary.

Eg: Lime (flux, agent) in SP,
↓
Scrubber
↳ Slurry (wet)
↓
BF.

⇒ Absorber: I) for product purification
But in IPC, we treat Gases of ppm level

so waste water need to be used instead of fresh water

→ Caustic shouldn't be used (cost is high) other alkaline sol be used.

↓

from water treatment → if not present then use lime.

→ Do not use conc. H_2SO_4 acid., use spent acid

Eg: Spent H_2SO_4 (chloro-alkali Industry)

→ Types of Scrubber:

i) Packed Tower
ii) Spray Tower
iii) Tray type tower scrubber.
iv) Bubble column scrubber.
v) Cyclonic Scrubber.
vi) Venturi scrubber.

Two p :- η, ΔP → high for tray tower Bubb

↓

ID fan

↓

power req is more

11/11/24.

⇒ Soluble gases

PM

⇒ PM → solvent req need not be designed

⇒ Soluble gases : HCl, HF

NH_3 MT

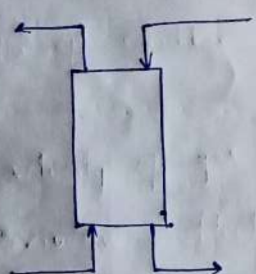
CO

Vol. Organic comp

HC.

⇒ % of gas to be removed.

⇒



See eqm relation.

Cal dia of the tower.

NTU.

①. A ammonia - air mixture containing 0.2% vol by of NH_3 is to be scrubbed with water @ 12°C in a wet scrubber with 1 in raschig ring. The gas and the water rates are 1170 kg/hr each is based on empty c/s area. Estimate the tower dia & ht req if 99% of ammonia entering the scrubber to b removed. The scrubber operate at 1 atm. pr. The equilibrium relation is $y^* = 0.746x$ where.

y^* = mol. fr of NH_3 in the air

x = mol. fr of NH_3 in the soln

Properties:

Diffusivity of the gas = 1.425×10^{-5} m²/s

viscosity of the gas = 1.70×10^{-5} Pa s

Diffusivity liq = 2.16×10^{-9} m²/s.

$\mu_{liq} = 1.03 \times 10^{-3}$ kg/ms.

$\rho_{gas} = 1.25$ kg/m³.

$\rho_{liq} = 1000$ kg/m³.

⇒ If high η (70-90%) low ΔP scrubbers

②. In a cement kiln, petroleum coke is used as a fuel. The flue gas from the kiln @ 250 000 m³/hr. is emitted and which contains dust particulate matter and SO_2. The inlet conc. of SO_2 is 130 g/m³ and PM is 4000 mg/m³. This flue gas is to be scrubbed with water as a solvent in a suitable wet scrubber to ensure desired removal of SO_2. It is required to remove SO_2 in such a way that the exit gas should not contain more than 80 mg/m³ of SO_2. The eqm relationship b/t water - SO_2 system governed by the eqn $x = 12.73y$

x, y = mole fraction (vol %)

The temp of gas is at 175°C and pressure of 1 atm. Design a suitable wet scrubber with the minimum amount of water req. for this scrubbing.

→ SO_2 130×10^3 - 80 ; η should be 95%.

$\left(\frac{L}{G}\right)_{min}$ ⇒ high flow rate of ○

dia of scrubber

(i) velocity of gas

maximum = flooding vel

$\frac{\pi}{4} D^2 \times V_{opt}$

$(V_{opt} \approx 0.75\, V_f)$

Sometimes D = 15 m.

Instead of one scrubber, we can take scrubbers in series.

A DAP fertilizer plant uses ammonia from imported ammonia and sulfuric acid manufactured from imported sulphur. The flue gas emitted through the stack of the plant contains NH_3 450 mg/Nm³ and flowrate of the flue gas emitted at 130°C at the rate of 350000 m³/hr. This flue gas is to be scrubbed with water/spent acid as a solvent in a suitable wet scrubber. It is essential that outlet conc. of NH_3 should not exceed 22 mg/Nm³. Design the wet scrubber. The eqm relation b/t NH_3-water system governed by the eqn $x = 12.73y$ where x, y = mol fraction (vol %). The temp of gas is at ~~175°C~~ 130°C & pressure at 1 atm. Design a suitable wet scrubber

→ Mass

Check temp drop for liq phase. T < 70-80°C.

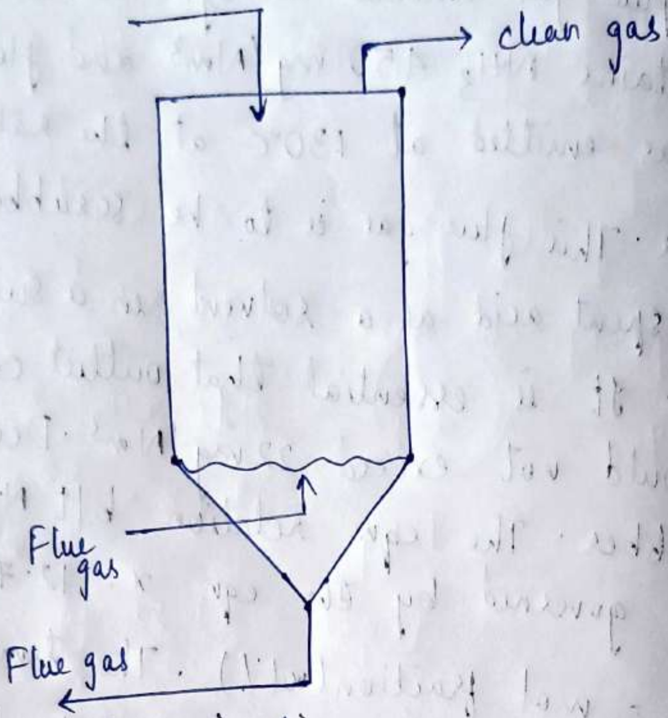
If T > 70°C, scrubber will be failed.

$T_{water} \ngtr 55-60°C$

T at $\left(\frac{L}{G}\right)$ T at $\left(\frac{L}{G}\right)_{min}$

NH_4OH $pH > 10$

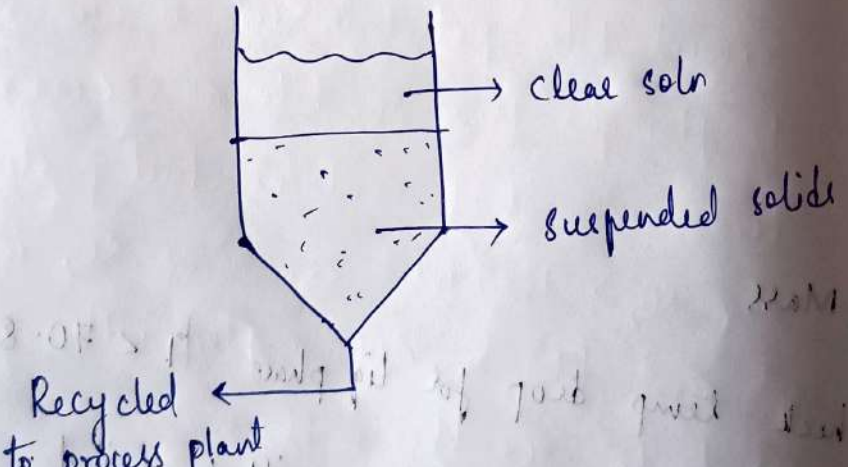
⇒



Gas ab in liq

NH_4OH ⟶ directly to Dm

$pH > 10$



Sometimes if the conc. is low, it can be recycled back to scrubber