

## Bag Filters

↳ Cleaning mechanism of Bag filters: —

→ Three main cleaning mechanism used in Bag filter:-

or shaking: Bags are mechanically shaken to dislodge the dust cake. Dust falls into the hopper below for disposal.

b) Reverse Air Cleaning: A gentle stream of reverse air (opposite to normal flow) is passed through the bags which flexes the bag, loosening the dust cake. Dusts drop into the hopper.

c) Pulse Jet Cleaning: short, high-pressure bursts of compressed air are injected through venturi tubes at the top of each bag. The shock waves dislodges the dust cake instantly.

→ challenges faced by industries using Bag filters:

or high maintenace requirements

b) Dust cake buildup  $\uparrow$  resistance to airflow. Fans must work harder to maintain flow  $\rightarrow$  higher power consumption.

c) Not ideal for very hot fine gas as fabric materials have temperature limits.

→ Choked Bags are identified: ↗ Increased pressure drop.  
Ruptured ~ ~ ~ : or suddenly decreases because air bypasses through holes.

End 2024

? Bagfilter operating at constant rate, filtration equation

$$V_G^2 = 2.623 \times 10^6 \times t \times P^{0.65}$$

$V_G^2$  = vol. filtered,  $m^3$ ;  $t$  = time, min;  $P$  = pressure, cm of water  
filtering time = 45 min with max<sup>m</sup> allowable pressure of 10 cm of water  
 $\rightarrow$  max<sup>m</sup> overall capacity

$\rightarrow$  two additional units are installed, at max<sup>m</sup> pressure  
as present. Total time eq. to shake and clean two  
units is estimated at 10 min. What max<sup>m</sup>  $P$  is  
the overall capacity that could be attained by  
adopting this suggestion?

$$\Rightarrow V_G^2 = 2.623 \times 10^6 \times t \times P^{0.65} \quad \left| \begin{array}{l} t = 45 \text{ min} \\ P = 10 \text{ cm} \end{array} \right.$$

Vol. filtered in one run

$$V_G = \sqrt{2.623 \times 10^6 \times 45 \times 10^{0.65}} = 2.3 \times 10^4 \text{ m}^3$$

for optimum capacity,  $t_f + 2t_c = 45 \text{ min}$

$$\therefore \text{Max}^m \text{ overall capacity} = \frac{2.3 \times 10^4}{90} = 255.56 \text{ m}^3/\text{min}$$

$$\therefore \text{New cleaning time } t_c = 10 \text{ min}$$

$$\text{No. of units} = 2+1=3 \quad P = 10 \text{ cm}$$

$$\text{New total cycle time} = 45 + 10 = 55 \text{ min}$$

$$\therefore \text{Overall capacity} = \frac{3 \times 2.3 \times 10^4}{55} = \frac{836.36}{55} \text{ m}^3/\text{min}$$

$$\therefore \frac{836.36 - 256.56}{256.56} \times 100 \approx \frac{226}{388.98}\%$$

End 2023

old bag filter from a discontinued process is to be utilised for constant pressure filtration at 140 mm water filter has 60 bags of  $8000 \text{ cm}^2$  each. Cleaning and shaking time observed as 20 min.

$$\text{filtration eq: } t = 674.82 V_G^2 \quad | \quad t = \text{time in min} \\ V_G = \text{vol. of gas filtered per unit area } (\text{m}^3/\text{cm}^2) \text{ of filter}$$

→ optimum overall capacity of filter

→ max<sup>m</sup> overall capacity.

→ if another 2 additional identical old units are installed to ↑ capacity, what is the max<sup>m</sup> % ↑ in overall capacity for new arrangement? Assume total cleaning time as 25 mins.

⇒ No. of bags = 60

Area of each =  $8000 \text{ cm}^2$

$$\therefore \text{Total surface area} = 60 \times 8000 = 480,000 \text{ cm}^2 \\ = 48 \text{ m}^2 = A$$

$$t_f = 20$$

→ Optimum overall capacity  $\Rightarrow \frac{V_G}{t_f + t_c}$

$$\text{Now, } t = 674.82 V_G^2 \Rightarrow 20 = 674.82 \times V_G^2$$

$$\Rightarrow V_G = 0.17216 \text{ m}^3/\text{cm}^2$$

Total vol filtered per cycle =  $V_G \times A$

$$= 0.17216 \frac{\text{m}^3}{\text{cm}^2} \times 480,000 \text{ cm}^2 \\ = 82636.8 \text{ m}^3$$

∴ Optimum overall capacity =  $t_f = t_c$

$$\Rightarrow \text{Opt. Q} = \frac{82636.8}{20+20} = 2065.92 \text{ m}^3/\text{min}$$

$$\rightarrow \text{Max capacity} = \frac{V_h}{t_f} = \frac{82636.8}{20} = 4131.84 \text{ m}^3/\text{min}$$

$$\rightarrow \text{With new arrangement} - \\ \text{total area } 3A = 3 \times A = 1,640,000 \text{ cm}^2$$

$$\text{Total cleaning time} = 25 \text{ min}$$

$$V_G = \sqrt{\frac{25}{674.82}} = 0.19254 \text{ m}^3/\text{cm}^2$$

$$\text{Total vol. per cycle} = 1,640,000 \times 0.19254 = 277257.6 \text{ m}^3$$

$$\text{cycle time} = 25 + 25 = 50 \text{ min}$$

$$Q_{3-\text{units}} = \frac{277257.6}{50} = 5545.15 \text{ m}^3/\text{min}$$

$$\therefore \uparrow = \frac{5545.15 - 2065.92}{2065.92} = 168.41$$

? 50,000 TPD plant has installed bag filter containing 144 bags of 30cm ID and 3m length. Capacity of ID fan provided is 40,000 m<sup>3</sup>/hr with 25 hoods of 450mm/600mm/800mm in site. The pressure drop across the bag filter is 70mm of water. Velocity of gas in main duct is 3.5 m/s. Predict ducting layout of the plant and calculate air to cloth ratio. State whether the capacity of ID fan is adequate or not.

$\Rightarrow$  Actual Vol. flowrate ( $Q_{\text{Actual}}$ ):

$$\text{Main Duct dia} = 50 \text{ cm} = 0.5 \text{ m}$$

$$\text{Main Duct Area} = \frac{\pi D^2}{4} = 0.1963 \text{ m}^2$$

$$\text{Gas velocity} = 3.5 \text{ m/s} \Rightarrow Q_{\text{Actual}} = 0.1963 \times 3.5 = 0.687 \text{ m}^3/\text{s}$$

$$= 41.23 \text{ m}^3/\text{min}$$

Now, Total filter cloth area ( $A_C$ ):

$$\text{Area of 1 bag} = \pi \times D \times L + \frac{\pi D^2}{4} = \pi \times 0.3 \left( 3 + \frac{0.3}{4} \right) = 2.89 \text{ m}^2$$

$$\text{No. of bags} = 144 \Rightarrow \text{Total cloth area} = 144 \times 3 = 432 \text{ m}^2$$

~~scrubbers~~

$$\text{Air to cloth ratio} = \frac{41.23}{432} = 0.095 \text{ m/min}$$

~~But recommended value = 1.2 to 2.5 m/min.~~

This suggests that bag filter is massively oversized for the system's actual flow.

$$i) Q_{\text{Actual}} = 41.23 \text{ m}^3/\text{min}$$

$$Q_{\text{given}} = 40,500 \text{ m}^3/\text{hr} = 666.67 \text{ m}^3/\text{min}$$

So, the ID fan capacity is adequate.

Ducting layout

Sources: 5 hoods are placed at the product separation unit to capture dust.

Collection: Each hood is connected to branch duct.

Transport: The 5 branch ducts merge into single main duct (ID 50cm)

Filtration: The main duct feeds the contaminated gas into the bag filter.

Exhaust: The ID fan is located after the bag filter, pulling the air through the entire system and exhausting the clean gas, likely to a stack.

A bag house is operated at cons. gas rate for 30 min.

? A bag house is operated at cons. gas rate for 30 min. during which  $70.8 \text{ m}^3$  of gas from a cement kiln operation is processed. The initial and final pressure drop of the unit is  $10.16 \text{ mm of water column}$ . If the filter is further operated for 1 hour at the final pressure calculate the quantity of additional gas which can be treated by this unit?

$$\Rightarrow Q = \frac{70.8 \text{ m}^3}{30 \text{ min}} = 2.36 \text{ m}^3/\text{min}$$

$$\text{Rate} = (A + J) \Delta P = \text{gas rate} \times \Delta P$$

? Bag house is ~~operated at const.~~ used to treat  $50 \text{ m}^3/\text{s}$  of the waste gas stream, the bag house to be divided into 8 sections of equal cloth area, so that 1 section can be taken off for shutdown for cleaning and maintenance & other remaining in working condition. The air to cloth area ratio is  $9 \text{ m}^3/\text{min.m}^2$  which provided sufficient surface area for the cleaning of the fine gas. The bags are  $25 \text{ cm dia}$  and  $7 \text{ m}$  long. Calculate the no. of bags and physical arrangement req. to meet the above purpose.

$$\Rightarrow Q = 50 \text{ m}^3/\text{s.} \quad | \quad L = 7 \text{ m} \\ D = 0.25 \text{ m}$$

$$\text{Air to cloth ratio} = 9 \text{ m}^3/\text{min.m}^2 \text{ cloth} = \frac{9 \text{ m}^3}{\text{min}} = D$$

$$\text{Area of cloth} = \frac{\text{flow of air}}{\text{Air to cloth ratio}} = \frac{50 \times 60}{D} = \frac{1000}{3} \text{ m}^2$$

$$\text{Area of each bag} = \pi D(L + D/4) = 5.55 \text{ m}^2$$

$$\therefore \text{No. of bag req.} = \frac{1000}{3 \times 5.55} \approx 60$$

As, bag house to be divided into 8 equal sections.  
So that one section can be shut down for cleaning.

The min<sup>n</sup> no. of bags req per each section —  
(7 operating section)

$$\frac{60}{7} \approx 8 \text{ bag.}$$

$$\therefore \text{Total bags req} = 8 \times 8 = 64 \quad \xrightarrow{\substack{\text{No. of} \\ \text{bag} \\ \text{per section}}}$$

## # Scrubbers

Q) Mention 5 wet scrubbers that are used for controlling gaseous emission from process plants.

Ans) Spray towers, Packed beds, Bubble or plate towers, Venturi scrubber, cyclonic scrubber

Q) Explain working principle of a multi-tray type wet scrubber (Plate tower) with design modification for large interfacial surface area with neat schematic diagram.

Ans) Plate Tower removes particulates and gaseous pollutants by contacting the contaminated gas stream with liquid droplets (usually water). It uses multiple perforated trays OR bubble-cap trays arranged vertically to increase gas-liquid contact surface area.

### Working Principle

- 1) Gas inlet: Dirty or polluted gas enters from the bottom
- 2) Liquid Distribution: Scrubbing liq. is sprayed over each tray
- 3) Gas-liquid contact: Gas passes through perforation, bubbling through the liq. layer on each tray forming fine bubbles.
- 4) Mass Transfer: Pollutants are tapped by liquid film due to impingement, diffusion, and absorption.
- 5) Mist Elimination: Clean gas passes through a demister before exiting to remove entrained droplets.
- 6) Collected Slurry: Pollutant-laden liq. drains down the bottom and is removed.

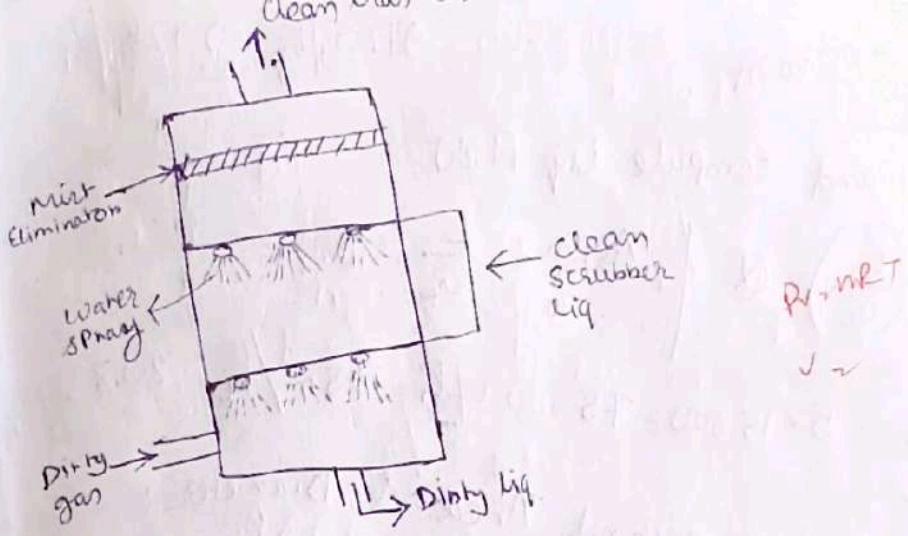
### Design Modification for Large Interfacial Area.

i) use of perforated trays with smaller holes

ii) multiple shallow trays to ↑ no. of contact stages.

iii) High liq. recirculation rate

iv) fine spray nozzles above trays to maximize droplet formation.



Q22 ? It is essential to remove  $H_2S$  from a flue gas from ore-smelting plant at  $15,000 \text{ m}^3/\text{hr}$ . Give detailed step by step design procedure of a wet scrubber of your choice to remove  $H_2S$  from flue gas with design eqn.

$$\Rightarrow \text{Gas flow} = 15,000 \text{ m}^3/\text{hr} = 4.1667 \text{ m}^3/\text{s} \quad \begin{matrix} \text{# Chorent type: counter-} \\ \text{current packed tower} \end{matrix}$$

Temp =  $25^\circ\text{C}$  and pressure =  $1 \text{ atm}$  molar vol =  $V_m = 0.02445 \text{ m}^3/\text{mol}$

$y_{\text{inlet}} \text{ of } H_2S = 200 \text{ ppmv} \quad y_{\text{out}} = 2 \text{ ppmv} \quad (99\% \text{ removal})$

consider superficial

scrubbing Agent:  $\text{NaOH}$

Packing material selection: Select a high efficiency, corrosion-resistant packing

Now,

$$\Rightarrow \text{Convert gas flow to molar flow} \Rightarrow n_G = \frac{Q}{V_m} = \frac{4.1667}{0.02445} = 170.42 \text{ mol/s.}$$

1) Determine  $H_2S$  molar flow and removal requirement —

$$y_{\text{in}} = 200 \times 10^{-6} \quad y_{\text{out}} = 2 \times 10^{-6}$$

$$\begin{aligned} \cancel{n_{H_2S, \text{in}}} &= n_G \cdot y_{\text{in}} = 170.42 \times 200 \times 10^{-6} \\ &= 0.03408 \text{ mol/s} = 122.7 \text{ mol/h} \end{aligned}$$

$$\text{Required removal (99\%)}: n_{H_2S, \text{rem}} = 0.99 \times 122.7 = 121.5 \text{ mol/h}$$

2) Stoichiometric reagent consumption —



$$\text{mol NaOH per mol } H_2S = 2$$

$$\therefore m_{NaOH} = 2 \times n_{H_2S, \text{rem}} \times 40 \text{ g/mol}$$

$$\text{MW}_{\text{NaOH}} = 40$$

$$m_{NaOH} = 2 \times 121.5 \times 40 = 9720 \text{ g/h} = 9.72 \text{ kg/h}$$

iv) choose  $L/G$  and compute liquid flow.

$$L = \left(\frac{L}{G}\right) \times Q \quad | \quad \text{Assume } \frac{L}{G} = 5$$

$$\therefore L = 5 \times 15,000 = 75,000 \text{ L/h} = 75 \text{ m}^3/\text{h} = 20.834 \text{ /s.}$$

v) column cross sectional Area & Diameter:

$$\text{let gas velocity } U_g = 1 \text{ m/s}$$

$$A_2 = Q/U_g = 4.17 \text{ m}^2 \Rightarrow D = \sqrt{\frac{4A}{\pi}} = 2.3 \text{ m}$$

vi) Mass Transfer design:

$$\text{Packed Height} \quad | \quad H_{\text{packing}} = HTU \times NTU$$

$$NTU \approx \ln\left(\frac{y_{in}}{y_{out}}\right) = \ln\left(\frac{200 \times 10^{-6}}{2 \times 10^{-6}}\right) = 4.605$$

$$HTU = \frac{G}{K_{G,a} A} \quad | \quad G = \text{molar gas flow per unit cross-section}$$

$$\frac{n_a}{A} = \frac{130.42}{4.17} = 40.0 \text{ mol/s.m}^2$$

$$HTU = \frac{40.0}{20} \quad | \quad \text{Assume } K_{G,a} = 20 \text{ s}^{-1}$$

↳ overall gas-phase  
mass transfer coeff. ( $\text{s}^{-1}$ )

$$H = 2.045 \times 4.605 \approx 9.4 \text{ m}$$

# Discuss the design procedure of packed column to remove soluble gaseous pollutants from a polluted gas stream with design equations.

2023  
? Which type of wet scrubber is preferred in handling large raw materials processing units and recycling?  
Explain the working principle of operation with diagram.

### ⇒ Venturi Scrubber

#### Working Principle

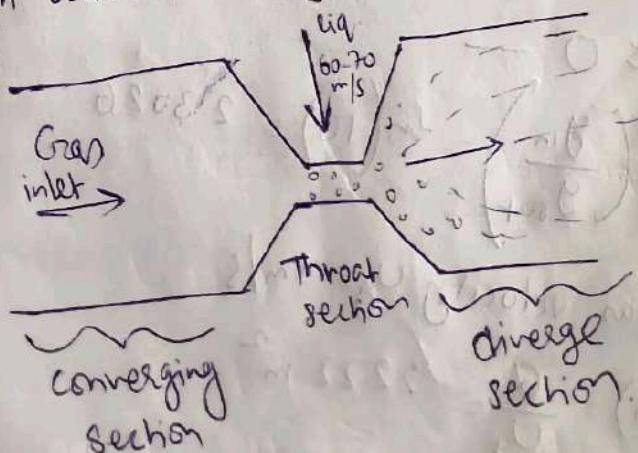
i) Gas Entry and Acceleration: The contaminated gas stream enters the converging section. As the area of the duct decreases, the vel. increases significantly due to the venturi effect.

ii) Liquid injection and Atomization: Scrubbing liquid (after water) is introduced into the gas stream, usually at the entrance of the converging section or at the throat section. The high velocity gas shears the liq. into vast no. of very fine droplets, creating a turbulent, high surface-area mist.

iii) Pollutant Capture: In the turbulent throat and the initial part of the diverging section, the fine liq. droplets collide forcefully with the fast-moving pollutant particles and gas molecules. The high relative velocity and intense mixing ensure trapping the pollutants within the liq. droplets.

iv) Separation: The pollutant containing heavy liq. droplets move to the diverging section where it slows down. This steam is then typically directed to a separate cyclonic separator, or mist eliminator.

v) Discharge and Recycle: The clean gas exits the system through outlet, meeting environment standards.



CTB

? A  $\text{H}_2\text{SO}_4$  acid plant emitting  $\text{SO}_2$  at  $800 \text{ ug/m}^3$  in a flue gas at  $450 \text{ K}$  and  $756 \text{ mmHg}$  with a flowrate  $80,000 \text{ m}^3/\text{hr}$ . This is to be scrubbed with water as a solvent in a absorber. It is req. to be maintained below  $80 \text{ ug/m}^3$  design a wet scrubber of your choice to meet the above req.

$$\Rightarrow Q = 80,000 \text{ m}^3/\text{hr} = 22.22 \text{ m}^3/\text{s}$$

$$T_2 = 450 \text{ K} \quad P = 756 \text{ mmHg} = 100791.73 \text{ Pa}$$

$$\text{SO}_2 \text{ inlet} = 800 \text{ ug/m}^3 \quad \text{SO}_2 \text{ out} = 80 \text{ ug/m}^3$$

$$\text{SO}_2 \text{ removal} = 90\%$$

$$M_{\text{SO}_2} = 64 \text{ g/mol.}$$

$$1) \text{ Molar vol (ideal gas)} \Rightarrow V_m = \frac{RT}{P} = \frac{8.314 \times 450}{100791.73} = 0.037 \text{ m}^3/\text{mol.}$$

$$2) \text{ Gas molar flow} \Rightarrow n_{\text{G}} = \frac{Q}{V_m} = \frac{22.22}{0.037} = 598.6 \text{ mol/s}$$

3)  $\text{SO}_2$  mole fraction —

$$C_{\text{in}} = \frac{800 \times 10^{-6}}{64} = 1.25 \times 10^{-5} \text{ mol/m}^3$$

$$\text{mole fraction}_{\text{in}} = C_{\text{in}} \times V_m = 1.25 \times 10^{-5}$$

$$C_{\text{out}} = \frac{80 \times 10^{-6}}{64} = 1.25 \times 10^{-6} \text{ mol/m}^3$$

$$Y_{\text{out}} = C_{\text{out}} \times V_m = 1.25 \times 10^{-8}$$

$$A = \pi D^2$$

4) Assuming  $y^* \approx 0$  —

$$NTU = \ln\left(\frac{y_{\text{in}}}{y_{\text{out}}}\right) = \ln(10) = 2.3026$$

5) Assuming gas velocity  $U_g = 1 \text{ m/s}$

$$\text{column Area (A)} = \frac{Q}{U_g} = 22.22 \text{ m}^2$$

$$\text{Diameter } D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \times 22.22}{\pi}} = 5.32 \text{ m.}$$

$$6) \text{ choose } L/G = 5 \text{ L/m}^3 \quad 1 \text{ m}^3 = 10^3 \text{ L}$$

$$\Rightarrow L = \frac{L}{G} \times Q = 5 \times 80,000 = 400,000 \text{ L/hr} = 400 \text{ m}^3/\text{hr}$$

7) Main Transfer Sizing:

$$\text{Packed height } H = \text{HTU} \times \text{NTU}$$

$$\begin{aligned} \text{NTU} &= 2.306 & \text{HTU} &= \frac{G}{K_G a} \\ && & G = \frac{n G_2}{A} = \frac{5986}{22.22} \\ && & = 26.94 \text{ mol/s.m}^2 \\ && & \text{assume: } K_G a = 20 \text{ s}^{-1} \\ \text{HTU} &= \frac{26.94}{20} \\ &= 1.35 \end{aligned}$$

$$\therefore H = 2.306 \times 1.35 \approx 3.10 \text{ m}$$

fixed  Re

8) in a zinc smelter plant the flue gas emitted after sulfur recovery is  $150,000 \text{ m}^3/\text{hr}$  and contains  $\text{SO}_2$ . The inlet conc.  $\text{SO}_2$  is  $600 \text{ ug/m}^3$ . This flue gas need to be treated in an wet scrubber with recycled water as a solvent to meet the stringent discharge limit of  $\text{SO}_2$ . It is req. to remove  $\text{SO}_2$  in such a way that the exit gas should not contain more than  $100 \text{ ug/m}^3$  of  $\text{SO}_2$ . The equilibrium relationship between  $\text{SO}_2$ -water system governed by the equation

$$x = 11.534 \cdot y \quad \text{where } x, y \text{ are in mole fraction (vol%).}$$

Temp of gas is at  $120^\circ\text{C}$  and Pressure of  $1.06 \text{ kg/cm}^2$ . Design a suitable wet scrubber with dimensions,  $m \text{ m}$  amount of water req. for this scrubbing and quantity of discharge wastewater generated.

$$\Rightarrow Q = 150,000 \text{ m}^3/\text{hr} \quad V_m = \frac{RT}{P} = \frac{8314 \times 393}{103950.5} \approx 0.03 \text{ m}^3/\text{mol}$$

$$\text{Gas molar flow } n_{G_2} = \frac{41.67}{0.03} = 1388 \text{ mol/s}$$

$$\text{Now, } C_{in} = 600 \text{ ug/m}^3 = \frac{600 \times 10^{-6}}{64} = 9.38 \times 10^{-6} \text{ mol/m}^3$$

$$C_{out} - \text{to out} \text{ ug/m}^3 = \frac{100 \times 10^{-6}}{64} = 1.56 \times 10^{-6} \text{ mol/m}^3$$

$$y = C_{in} \cdot V_m$$

$$y_{in} = C_{in} \cdot V_m = 0.2044$$

$$y_{out} = 0.049$$

NOW, min<sup>m</sup> molar L/G (fresh water,  $x_{in} \approx 0$ )  
 equilibrium relation:  $x_2 = 11.534 y$  |  $m = 11.534$

Material balance:  $\frac{L}{G} \left|_{min} \right. = \frac{y_{in} - y_{out}}{m \cdot y_{out}}$

$y_{in} = 0.2944$  |  $x_{in} = 0$   
 $x_{max} = 0.2944 \times y_{in}$   
 $= 11.534 \times 0.29 = 3.34$

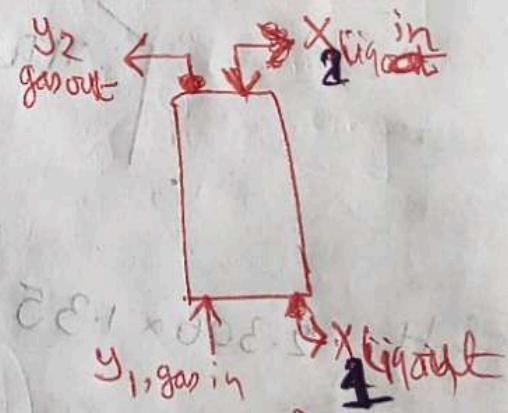
$\frac{L}{G} \left|_{min} \right. = \frac{y_{in} - y_{out}}{m \cdot y_{out}} = \frac{0.2944 - 0.049}{11.534 \times 0.29} = 0.4335$

$L_{min} = \frac{0.2944 - 0.049}{3.34} \approx 0.0734$

$$\Rightarrow L_{min} = Q \times 0.0734$$

$$= 61.67 \text{ m}^3/\text{s} \times 0.0734$$

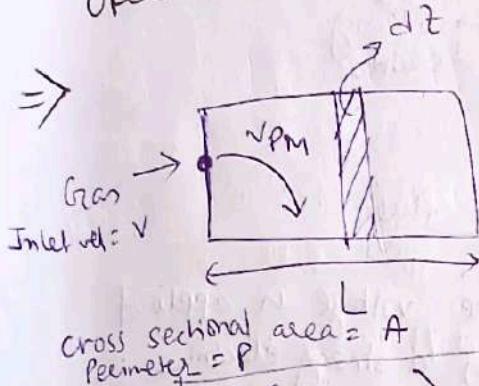
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$$Q(y_1 - y_2) = L(x_2 - x_1)$$

# ESP

? Derive Exp. for collection efficiency of particle in an ESP from fundamentals of operations.  
Describe challenges faced by installation and operation of ESP.



Mass balance —  
 $J_m = \text{out} + \text{Particle collected on collecting electrode}$

$$\text{cross sectional area} = A \\ \text{Perimeter} = P$$

$$\Rightarrow AV(C_{in} - C_{out}) = V_{PM} \times P \times dz \times C$$

$$\Rightarrow AV \int \frac{dC}{C} = -V_{PM} \times P \int dz$$

$$C_{in} = C_0$$

$$\Rightarrow AV \ln \left( \frac{C_L}{C_0} \right) = -V_{PM} \times P \times L$$

$$\Rightarrow \frac{C_L}{C_0} = \exp \left( -\frac{V_{PM} \times P \times L}{A \times V} \right)$$

$$\Rightarrow n = \frac{C_L - C_0}{C_0} = 1 - \exp \left( -\frac{V_{PM} \times A_c}{Q \times V} \right)$$

$$Q = A \times V = \text{flow rate}$$

$$A_c = \text{collecting surface area}$$

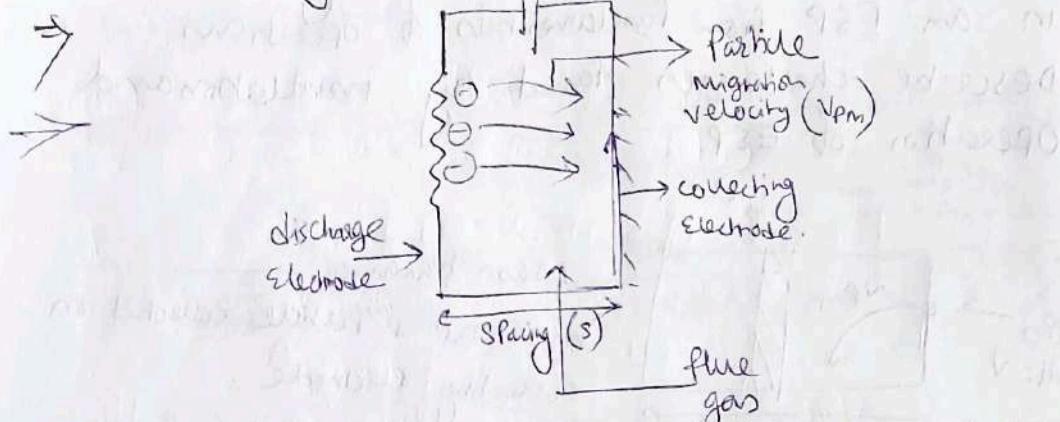
$$V_{PM} \approx 0.18 - 0.2 \text{ m/s}$$

→ challenges:

- if high capital cost
- if design complexity

- dust accumulation and re-entrainment
- electrical issues

? mechanism of Particle charging in ESP and how efficiency is related to such mechanism?



Step 1: Corona discharge: high -ve voltage is applied to discharge electrodes. This creates a strong electric field, ~~around the wire~~ ionizing the ~~wire~~ surrounding gas → generating -ve ions. This region of ionization is known as corona discharge.

Step 2: Ion-particle collision (charging)

There are two types of charging mechanism —

↗ Field charging: Particles are directly charged in the electric field.

↗ Diffusion charging: Random motion of ions causes them to stick to very fine particles.  
Fine particles harder to charge → difficult to collect

$$\Rightarrow \eta = 1 - e^{-\frac{V_{pm} \cdot A}{Q}}$$

$V_{pm}$  = Particle migration velocity  
 $A$  = collection plate Area  
 $Q$  = gas flow rate

183  
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More charge → greater electric field → higher migration velocity.  
 higher migration velocity → faster particles reach collecting electrode → higher  $\eta$ .

2024

? ESP having dim<sup>h</sup> as 4m high, 5m depth with spacing between the plates as 40 cm separate dust from a flue gas at a temp. of 175°C and 1.01 kg/cm<sup>2</sup>. The gas flows through the precipitation at a rate of 250,000 m<sup>3</sup>/hr where ~~volt~~ voltage is varying as

$$V_s = (4S^3 + 2.5) \times 10^5 \text{ volt}, S = \text{spacing}.$$

Particle size analysis shows the distribution —

D <sub>p</sub> (micron)	0.5	1	2	4	5	10	20
% Weight	5	22	27	23	8	4	Rest

Assume diffusional mechanism predominates, the particle charging.  $C = 1 + \frac{0.172}{d_p}$ , d<sub>p</sub> is particle dia in micron.

calculate —

- i) Particle migration velo.
- ii) Overall collection efficiency of ESP.
- iii) If spacing  $\uparrow$  5cm, what would be % change in overall collection efficiency keeping all other parameters constant?
- iv) Draw migration vel. profile across the entire size range of particle.

$$\Rightarrow h = 4 \text{ m} \quad \text{Collection Area } A_c = 2rh \times l = 40 \text{ m}^2 \\ (l = 5 \text{ m.}) \quad \text{Spacing: } 40 \text{ cm}^2 = 0.4 \text{ m.}$$

$$Q = 250,000 \text{ m}^3/\text{hr} = 6944 \text{ m}^3/\text{sec.}$$

$$V_s = (4 \times (0.4)^3 + 2.5) \times 10^5 = 275600 \text{ Volt}$$

$$E = \text{Electric field: } V_s / S = 689,000 \text{ V/m.}$$

$$T = 175^\circ\text{C} \\ P = 1.01 \text{ kg/cm}^2 \\ = 99047.17 \text{ Pa.} \\ \mu = 2 \times 10^{-5} \text{ Pa.s @ } 175^\circ\text{C}$$

$$i) \text{Particle migration velocity } V_{pm} = \frac{qE \times C}{3\pi \times \mu \times d_p} \quad q = n \times 1.6 \times 10^{-19} \\ n = \frac{PV}{RT}$$

$$V = H \times D \times S \\ = 4 \times 5 \times 0.4 \\ = 8 \text{ m}^3$$

$$\therefore n = \frac{99047.17 \times 8}{8.314 \times 448} = 212.74$$

$$\therefore q = 212.74 \times 1.6 \times 10^{-19} \\ = 3.4 \times 10^{-17}$$

$$\text{i)} \quad V_{PM} = \frac{3.4 \times 10^{-17} \times 680000 \times C}{13 \times 3.14 \times 2 \times 10^{-5} \times dp} = \frac{1.24 \times 10^{-2} \times C}{dp}$$

$dp(\mu\text{m})$	$\omega_i(w_i) \text{ } C$	$V_{PM}(\text{m/s})$	$\eta_i$	$\eta_i \times w_i$
0.5	5	1.344	0.048	0.033
1	22	1.172	0.124	0.068
2	27	1.086	0.062	0.035
4	23	1.043	0.031	0.018
5	48	1.034	0.025	0.014
10	14	1.017	0.0124	$1.12 \times 10^{-3}$
20	11	1.0086	$6.2 \times 10^{-3}$	$3.56 \times 10^{-3}$

$$\text{ii)} \quad \text{collection efficiency} (\eta_i) = 1 - \exp\left(-\frac{V_{PM} \times A_c}{Q}\right)$$

$$\text{iii)} \quad \eta_{\text{overall}} = \sum \eta_i w_i = 1.382 = 138.2\%$$

for change of spacing, need to calculate the area of entire filter with  $S' = 45 \text{ cm}^2 = 0.45 \text{ m}^2$

$$\eta = 1 - \exp\left(-\frac{V_{PM} \times A_c}{Q}\right) \quad \frac{V_{PM} \times S'}{Q} \rightarrow V_{PM_2} = \frac{S_2}{2} \times V_{P_1}$$

$$A_c = h \times l \times S'$$

$$Q = 69.44 \text{ m}^3/\text{s}$$

$$\eta_i \Rightarrow \sum \eta_i w_i$$

$$V_{PM} \propto \frac{1}{S}$$

? Parallel Plate ESP having dimension as 4m h, 6m depth with spacing b/w the plates 30cm separate duct from a flue gas at a temp of  $130^{\circ}\text{C}$  and  $1.03 \text{ kg/cm}^2$ .  $Q = 70,000 \text{ m}^3/\text{hr}$  where voltage = 70,000V. Particle size analysis —

$D_p (\text{micron})$	0.05	0.1	0.2	0.4	0.8	1.2	5
% weight	1	16	25	28	10	16	2
$C = 1 + \frac{0.17}{dp}$							

calculate —

- a)  $V_{PM}$  b)  $\eta_{overall}$  c)  $\eta_{overall}$  if T of flue gas  $\uparrow$  to  $150^{\circ}\text{C}$ .
- d) if spacing is  $\uparrow$  by 10cm, what would be % change in overall collection efficiency.
- e) prepare a grade efficiency profile of the entire range of particles.

$$\Rightarrow h = 6\text{m} \quad l = 6\text{m} \quad \text{Spacing} = 30\text{cm} = 0.3\text{m.} \quad \mu = 2 \times 10^{-5} \text{ Pa.s} \\ \text{Collection Area} = 2 \times 6 \times 6 = 48 \text{ m}^2 \quad T = 130^{\circ}\text{C} = 403\text{K} \quad Q = 70,000 \text{ m}^3/\text{hr} \\ (AC) \quad = 48 \text{ m}^2 \quad P = 1.03 \text{ kg/cm}^2 = 101008.5 \text{ Pa} \quad = 19.44 \text{ m}^3/\text{s.} \\ C = 1 + \frac{0.17}{dp} \quad V = 70,000 \text{ Volt}$$

NOW,  $V_{PM} = \frac{q_B \times E \times C}{3 \times \pi \times \mu \times dp}$

$$n = \frac{PV}{RT} = \frac{101008.5 \times 7.2}{8.314 \times 403} = 2170.6 \text{ N/m}^3$$

$$q_B = 0.19 \times 10^{-9} \text{ A}^2 \quad g_B = n \cdot e$$

$$q_B = 0.19 \times 10^{-9} \text{ A}^2 \quad E = \frac{0.19 \times 10^{-9} \times d_p \times E}{4} \quad E = \frac{V}{S} \\ = \frac{0.19 \times 10^{-9} \times d_p \times 7.2}{4 \times 0.3} = \frac{70,000}{0.3} = 233333 \text{ V/s}$$

$$V_{PM} = \frac{0.19 \times 10^{-9} \times d_p \times E \times C}{3 \times 4 \times \pi \times 2 \times 10^{-5} \times d_p} = \frac{2.52 \times 10^{-12} \times (233333)^2 \times C}{10^{-5}} \\ = 13726.70 \times C \times d_p = 13726.7 \times \left(1 + \frac{0.17}{dp}\right) \times d_p \\ = 13726.7(0.17 + dp)$$

$d_p(\mu m)$	$w_i(w_i)$	$V_{pm}(\text{m/s})$	$\eta_i$	$\eta_i \times w_i$
0.05	1	$3 \times 10^{-3}$	$7.38 \times 10^3$	$7.38 \times 10^{-5}$
0.1	16	$3.7 \times 10^{-3}$	$0.09 \times 10^{-3}$	$1.45 \times 10^{-3}$
0.2	25	$5 \times 10^{-3}$	0.012	<del>3/1000</del> 0.003
0.4	28	$7.8 \times 10^{-3}$	0.019	0.0053
0.8	10	$13.314 \times 10^{-3}$	0.032	0.0032
1.2	16	$18.805 \times 10^{-3}$	0.045	0.0072
5	2	$20.967 \times 10^{-3}$	0.16	0.0032

Now,

$$\eta = 1 - \exp\left(-\frac{V_{pm} \times A_C}{Q}\right) \quad \left| \begin{array}{l} A_C = 48 \\ Q = 19.64 \text{ m}^3/\text{s} \end{array} \right.$$

$$\eta_{\text{overall}} = \sum \eta_i w_i = 0.023 = 2.3\%$$

Now, for  $T=15^\circ\text{C}$ ,  $\mu = 2.3 \times 10^{-5} \text{ Pa.S}$

$$V_{pm} = \frac{q \times F \times C}{3 \pi \times \mu \times d_p} = 11036.2 \left(1 + \frac{0.17}{d_p}\right) \text{ m/s}$$

→ calculate  $V_{pm}$  for every  $d_p$

$$\rightarrow \eta_i$$

$$\rightarrow \eta_i \times w_i \Rightarrow \sum \eta_i w_i = \text{overall efficiency}$$

(should decrease due to high viscosity)

d) if Spacing increased —

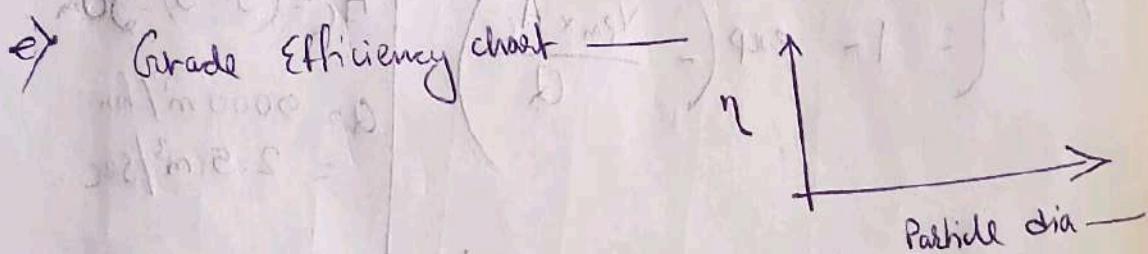
$$\frac{V_{PM_1}}{V_{PM_2}} = \frac{s_2}{s_1} \Rightarrow V_{PM_2} = \frac{s_1}{s_2} \times V_{PM_1}$$

$$= \frac{0.3}{0.4} \times V_{PM_1}$$

↳ Again calculate  $\eta_i$

↳  $\sum(\eta_i \times w_i)$  → calculate % change

e)



$$(m)(C_1 - \eta_{10}) \quad (m)(C_1 - \eta_{10})$$

$$NEE\% = \frac{\eta_1}{C_1} + \frac{1-C_1}{C_1} = \frac{(C_1 - \eta_1)}{C_1}$$

$$\left( \frac{C_1 - \eta_{10}}{C_1} \right) q_{10} + 1 = \frac{100\%}{C_1} \eta_{10}$$

$$f_{100\%} = \left( \frac{C_1 - \eta_{10}}{C_1} \right) q_{10} \times$$

$$2 | m \text{ C.S.O} = M.S.V |$$

$$2 | m \text{ C.S.O} = M.S.V |$$

$$\left( \frac{C_1 - \eta_{10}}{C_1} \right) q_{10} + \left( \frac{A_{max}}{k} \right) q_{10} + 1 = f_{100\%}$$

? horizontal parallel plate ESP having  $h = 3\text{ m}$ , depth  
 $= 5\text{ m}$ , spacing = 20cm.  $Q = 9000 \text{ m}^3/\text{hr}$ .  
 inlet and outlet loadings are  $15\text{ g/m}^3$  and  $1\text{ g/m}^3$ . determine -

i)  $\eta$       iii)  $\eta @ Q = 30,000 \text{ m}^3/\text{hr}$

ii)  $V_{pm}$       iv) % change in  $\eta$  when  $S \downarrow \cancel{5\text{ cm}}$

$$\Rightarrow \eta = 1 - \exp\left(-\frac{V_{pm} \times A_C}{Q}\right) \quad \left| \begin{array}{l} A_C = (3 \times 5) = 30 \text{ m}^2 \\ Q = 9000 \text{ m}^3/\text{hr} \\ = 2.5 \text{ m}^3/\text{sec} \end{array} \right.$$

$V_{in} = 15 \text{ g/m}^3$        $C_{out} = 1 \text{ g/m}^3$

$$\eta_2 = \frac{C_{in} - C_{out}}{C_{in}} = \frac{15 - 1}{15} = \frac{14}{15} = 0.9333.$$

ii)  $\frac{93.33}{100} = 1 - \exp\left(-\frac{V_{pm} \times 30}{2.5}\right)$

$$\Rightarrow \exp\left(-\frac{V_{pm} \times 30}{2.5}\right) = 0.067$$

$$\Rightarrow V_{pm} = 0.23 \text{ m/s.}$$

iii) when  $Q = 30,000 \text{ m}^3/\text{hr} = 8.33 \text{ m}^3/\text{sec.}$

$$\therefore \eta = 1 - \exp\left(-\frac{V_{pm} \times A_C}{Q}\right) = 1 - \exp\left(-\frac{0.23 \times 30}{8.33}\right)$$

$$= 0.5632$$

$$\Rightarrow \eta_2 = 56.32\%$$

$$\text{iv) } V_{PM} \propto \frac{1}{S} \Rightarrow \frac{V_{PM_2}}{V_{PM_1}} = \frac{S_1}{S_2} \Rightarrow V_{PM_2} = 0.23 \times \frac{20}{15} = 0.3$$

$$\therefore \eta = 1 - \exp\left(-\frac{0.3 \times 30}{8.33}\right) = 0.66$$

$\therefore \eta = 66\%$

$$\therefore \text{change in } \eta = \frac{66 - 63.33}{63.33} = 2.28\% \quad (\downarrow)$$

## Cyclone Separation

- ? Expression for  $D_{pc}$  in a conventional cyclone separator from basic balances. Significance of  $D_{pc}$  for selecting the cyclone separator.
- ⇒ Significance: cut size particle dia. represents particle size with 50% collection efficiency and is a primary indicator of the separator's performance.

$$D_{pc} = \left( \frac{9 \times \mu_g \times b}{2 \times \pi \times N_e \times V_i \times (\rho_p - \rho_g)} \right)^{1/2}$$

$$n = \frac{1}{1 + \left( \frac{D_{pc}}{d_p} \right)^2}$$

$\mu_g$  = dynamic viscosity of gas ( $\text{kg}/\text{m}\cdot\text{s}$ )

$b$  = inlet width of cyclone (m)

$N_e$  = no. of turns

$V_i$  = ~~inlet~~ inlet vel. of gas ( $\text{m}/\text{s}$ )

$\rho_p$  = density of particles ( $\text{kg}/\text{m}^3$ )

$\rho_g$  = density of gas ( $\text{kg}/\text{m}^3$ )

B. mid

? conventional cyclone of dia = 1200 mm. containing Particulate of  $\rho_p = 12 \text{ g/m}^3$  at  $125^\circ\text{C}$  1 atm pressure.

$$V_{inlet} = 18 \text{ m/s}$$

$$N = 5$$

$$\rho_p = 2500 \text{ kg/m}^3$$

$$\rho_g = 1.29 \text{ kg/m}^3$$

$$\mu_F = 0.0117 \text{ cP}$$

i) cut size . particle diameter

ii)  $D_{P_{100}}$

iii) Overall collection efficiency of cyclone

particle size ( $\mu\text{m}$ )	> 70	70-40	40-30	30-20	20-15	15-10	10-5	< 5
% by wt.	15	14	9	13	10	20	8	11

$$\Rightarrow D_{P_c} = \left[ \frac{g \times \mu_F \times b}{2 \times N \times V \times (\rho_p - \rho_g)} \right]^{1/2}$$

$$\mu_F = 0.0117 \times 10^{-3} \text{ kg/m.s}$$

$$D_C = 1200 \times 10^{-3} \text{ m}$$

$$N = 5$$

$$V = 18 \text{ m/s}$$

$$< 5 \mu\text{m} = 11 + 8 = 19\%$$

$$> 5 \mu\text{m} = 100 - 19 = 81\% > 75\% \rightarrow \text{high efficiency cyclone.}$$

$$\therefore b = 0.2 D_C$$

$$\therefore D_{P_c} = \left[ \frac{g \times 0.0117 \times 10^{-3} \times (0.2 \times 1.2)}{2 \times 5 \times 18 \times 2500} \right]^{1/2} \quad | (\rho_p - \rho_g) \approx \rho_p$$

$$\therefore D_{P_{100}} = \left[ \frac{g \times \mu_F \times b}{N \times V \times (\rho_p - \rho_g)} \right]^{1/2}$$

$$\Rightarrow \eta = \frac{1}{1 + \left( \frac{D_{pc}}{D_p} \right)^2}$$

2023 end

\* High efficiency cyclones are used to remove high particle removal with a high pressure drop, while high-throughput cyclones are designed to handle large vol. of gas with low-pressure drop.

→ cyclone performance depends on —

i) Particle size

ii) Particle density

iii) Dust loading

\* Scaleup cyclone design —

$$\text{Scaling factor } \frac{d_2}{d_1} = \left( \frac{D_2}{D_1} \right)^{0.5} \left( \frac{\mu_2}{\mu_1} \right)^{0.5} \left( \frac{\Delta P_1}{\Delta P_2} \right)^{0.5} \left( \frac{Q_1}{Q_2} \right)^{0.5}$$

$d_1, d_2 \rightarrow$  cut diameters of the standard and proposed cyclones.

$D_1, D_2 \rightarrow$  diameters of standard, proposed cyclones

$\mu_1, \mu_2 \rightarrow$  gas viscosities

$\Delta P_1, \Delta P_2 \rightarrow$  density differences

$Q_1, Q_2 \rightarrow$  flow rates

exm: standard cyclone with  $D_1 = 0.203\text{m}$ ,  $Q_1 = 223\text{m}^3/\text{h}$

viscosity  $\mu_1 = 0.018 \times 10^{-3} \text{ kg/m.s}$

density difference ( $\Delta P_1$ ) =  $2000 \text{ kg/m}^3$

we need to design a system which can handle ~~atmos~~

$Q_2 = 5000 \text{ kg/m}^3$  ( $\mu_2 = 0.02 \times 10^{-3} \text{ kg/m.s}$ ,  $\Delta P_2 = 2800 \text{ kg/m}^3$ )

S<sub>1</sub>: Estimate No. of cyclones: Let's take 4 cyclone in parallel

$$\therefore Q_{\text{per-cyclone}} = \frac{5000}{4} = 1250 \text{ m}^3/\text{h}$$

$$S_2: \text{determine } D_2 \Rightarrow A_1 = 0.5 D_C \times 0.2 D_C = 0.1 D_C^2$$

$$A_2 = \frac{1250}{V_{\text{inlet}}} = \frac{1250}{3600 \times 1.5} \approx 0.0231 \text{ m}^2 \quad \left| \begin{array}{l} 0.1 D_C^2 = 0.023 \\ \Rightarrow D_C = 0.481 \text{ m} \end{array} \right.$$

Calculate Scaling factor

$$SF = \frac{D_2}{D_1} = \left( \frac{D_2}{D_1} \right)^{1.5} \times \left( \frac{Q_1}{Q_2} \right)^{0.5} \times \left( \frac{\Delta P_1}{\Delta P_2} \right)^{0.5} \times \left( \frac{U_2}{U_1} \right)^{0.5}$$

$$SF = \left( \frac{0.481}{0.203} \right)^{1.5} \times \left( \frac{223}{1250} \right)^{0.5} \times \left( \frac{2000}{2800} \right)^{0.5} \times \left( \frac{0.02 \times 10^{-3}}{0.018 \times 10^{-3}} \right)^{0.5}$$

$$SF \approx 1.43$$

## Surface Runoff

2021

?	Site description	Site Area ( $A_i$ ) (in Acres)	C-value (max) ( $C_i$ )
	Buildings	25.00	0.95
	Roads/Pavements	71.87	0.95
	Woodland	37.52	0.25
	Sandy Soil	53.06	0.10
	Heavy Soil	2.87	0.17
	Drainage Area	2.42	0.95
		Total Area = 193 Acres	

$$\text{Weighted run-off coefficient } C_w = \frac{\sum A_i \times C_i}{\sum A_i} = \frac{109.58}{193} \approx 0.568$$

Now, the pond must be designed for max<sup>m</sup> expected  
run-off volume.

Largest rainfall = 2.287 m

$$V = \text{Rainfall (m)} \times \text{Total area (m}^2\text{)} \times C_w$$

$$= \text{Rainfall} \times \sum(A_i \times C_i) = 2.287 \times \frac{44354.48}{109.58}$$

$$= 1014180.48 \text{ m}^3$$

Now, if we assume, the depth of pond = 5 m

$$\text{Then area of pond} = \frac{1014180.4}{5} = 202836.08 \text{ m}^2$$

$$\therefore \frac{202836.08}{781043.21} \approx 26\% \text{ of total area.}$$

? if it is req. to supply domestic use water from the nearest river Kansabati to IIT campus through pipeline. Explain the various treatment techniques involved to purify and supply water.

⇒ i) Intake and Screening:

Water is drawn from the river into the treatment plant. The raw water is passed through coarse and fine screens to remove debris, smaller suspended solids etc.

ii) Aeration: Water is brought into contact with

air to remove dissolved gases like  $H_2S$ ,  $CO_2$ . This also increases dissolved oxygen which helps to oxidise  $Mn^{2+}$ ,  $Fe^{2+}$ , ~~etc~~ converting them to insoluble particles that can be removed.

iii) Coagulation: Chemical coagulants like  $Al_2(SO_4)_3$  are added rapidly to neutralise negative charges.

iv) Flocculation: Water is gently stirred in a flocculation tank for 20-40 mins. This slow mixing promotes contact between the micro-flocs, causing them to aggregate into larger flocs.

v) Sedimentation: Water flows through a large sedimentation tank. Due to reduced velocity, dense flocs settle under the influence of gravity, forming a sludge layer which is removed periodically.

vi) Filtration: Clarified water is passed through sand filter beds to remove remaining suspended particles.

vii) Disinfection: Before supplying the water, water is disinfected using chlorination. Other methods are UV disinfection, Ozonation.

viii) pH adjustment: lime or soda is used to increase pH.  $\text{CO}_2$  or mild acids are used to lower the pH.

ix) Storage and supply: finally the clean water is stored in a clear water Reservoir (CWR)

is stored in a clear water Reservoir (CWR). The water is then pumped and storage tanks. The water is then pumped through the pipeline network to each domestic taps.

? Flowsheet for industrial Wastewater Treatment for Recycling.

→ i) Equilization Tank: Raw effluent is collected to homogenize the flow rate and pollutant concentration variations, ensuring a steady feed to the subsequent treatment units.

ii) Primary treatment: Removes large solids, debris and heavy inorganic particles to protect pumps and downstream equipment.

iii) Coagulation and flocculation:

iv) Sedimentation:

v) Aeration Tank:

vi) Filtration

vii) Adsorption: Removes color, odour and taste.

viii) Reverse Osmosis : Essential for recycling, if high purity is needed. Removes dissolved salts, heavy metals and ions.

ix) Disinfection:

→ Types of flocculants:

Inorganic : Poly-Aluminium Chloride (PAC)

Feeric Chloride ( $FeCl_3$ )

Synthetic : PAM : Poly acrylamides

Natural : starch,

(TSS separation in F.T.P (sedimentation))

→ Mechanism of TSS separation in F.T.P (sedimentation)

→ Measurement of COD and TSS in Wastewater Sample:

$$TSS(\text{mg/l}) = \frac{(\text{Weight of filter paper} + \text{solids}) - (\text{initial weight of filter paper})}{\text{Vol. of sample filtered (l)}}$$

COD : is measure of amount of oxygen equivalent required to chemically oxidise all organic and inorganic compounds in the sample. COD is measured using "Dichromate method".

BOD : Amount of dissolved oxygen required by aerobic micro-organisms to break down the biodegradable organic matter present in sample.

Measured using BOD<sub>5</sub> test

- ? SELECT a industry and show with flow sheet how Zero Liquid Discharge (ZLD) is possible.
- collection → screening → Equilization tank  
 ➤ pH correction → Coagulation - Flocculation →  
 sedimentation → filtration → Reverse Osmosis  
 ➤ Evaporation to crystallise salts → Solid waste  
 handling → ~~water~~ Recycle

? Peak rate of Surface Runoff water calculation

A) Rational Method:

$$Q_p = C \times i \times A$$

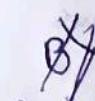
$Q_p$  = Peak run-off ( $m^3/\text{day}$ )

C = runoff coefficient

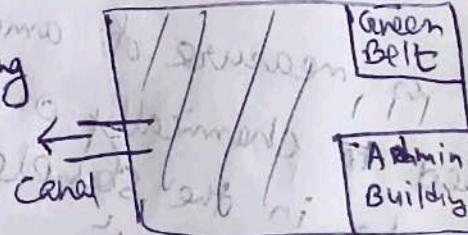
i = rainfall intensity ( $\text{mm/day}$ )

A = drainage area (~~ha~~)  
acres

➤ Find out the area where heavy rainfall has caused



➤ Then calculate area excluding green belt.



➤ High conc. Pollutant will go out via canal.

➤ zero lig. Discharge

➤ collect rainfall data from IMD and find out avg. data

➤ Finally multiply.

2021

Q = 150 m<sup>3</sup>/h       $BOD_5^{20} = 400 \text{ mg/L}$

$\left\{ \begin{array}{l} K = 0.23/\text{day} \\ \theta = 1.047 \end{array} \right. \quad | \quad BOD_{10}^{30} = ?$

$L = L_0 e^{-Kt}$

$\therefore \text{BOD removal} = \frac{L - L_0}{L_0} = L_0 (1 - e^{-Kt})$

$\Rightarrow L_0 = \frac{BOD_5}{1 - e^{-Kt}}$

$\therefore BOD_{10}^{30} = BOD_{\text{ultimate}} = \frac{BOD_5^{20}}{1 - e^{-Kt}}$

$= \frac{400}{1 - \exp(0.23 \times 5)} = 585.34 = L_0$

Now,  $K(30^\circ) = K(20^\circ) \times \phi^{30-20} = 0.23 \times 1.047^{10} = 0.36 \text{ day}^{-1}$

$\therefore L_0 = \frac{BOD_{10}^{30}}{1 - \exp(-10 \times 0.36)} = 585.34$

$\Rightarrow BOD_{10}^{30} \approx 570 \text{ mg/L}$

$\Rightarrow \text{efficiency} = \frac{\text{Fraction of BOD removed}}{\frac{BOD_{10} \times 100}{L_0}} = \frac{585.34 - 570}{585.34} \times 100 = 2.6\%$

$= \frac{BOD_{10} \times 100}{L_0} = \frac{570}{585.34} \times 100 = 97.4\%$

Q = 250 m<sup>3</sup>/hr       $BOD_5 = 300 \text{ mg/L}$

N = 4, d = 4, W = 5, L = 25

MLVSS = 2800 mg/L = 2.8 g/L

$\Rightarrow \text{Total vol.} = 4 \times (4 \times 5 \times 2.5) = 2000 \text{ m}^3$

$\Rightarrow \text{Detention time} = \sqrt{Q} = \frac{2000}{250} = 8 \text{ hrs}$

$\Rightarrow \text{vol. organic load} = \frac{\text{BOD load}}{\text{vol. aeration}}$

$= \frac{1800}{2000} = 0.9 \text{ kg/m}^3 \cdot \text{day}$

$\left\{ \begin{array}{l} \text{BOD load} = Q \times \text{BOD}_{\text{con.}} \\ = 250 \frac{\text{m}^3}{\text{hr}} \times 300 \text{ mg/L} \\ = (250 \times 24) \frac{\text{m}^3}{\text{day}} \times \frac{300 \text{ kg/m}^3}{1000} \\ = 1800000 \text{ kg/day} = 1800 \text{ kg/day} \end{array} \right.$

$$\Rightarrow \text{Sludge Loading Ratio (F/M)} = \frac{\text{kg BOD/day}}{\text{Mn of MLVSS in aeration tank}}$$

$$= \frac{1800}{5600} = 0.321$$

$$\left| \begin{array}{l} \text{Mn of MLVSS} \\ = 2.8 \text{ g/L} \times \text{Vol} \\ = \frac{2.8}{1000} \times 10^3 \frac{\text{kg}}{\text{m}^3} \times 2000 \text{ m}^3 \\ = 5600 \text{ kg} \end{array} \right.$$

2023

$$? Q = 100,000 \text{ gallon/day} = 37854 \text{ L/day}$$

$$\text{BOD}_5 = 250 \text{ mg/L} \rightarrow 40 \text{ mg/L}$$

i) kg of BOD entering the FTP per day

$$\text{BOD}_5 (\text{kg/day}) = \frac{250 \times 37854}{10^6} = 94.64 \text{ kg/day}$$

ii) % removal of BOD

$$\text{BOD}_{\text{out}} = \frac{40 \times 37854}{10^6} = 15.14 \text{ mg/day}$$

$$\Rightarrow \text{Removal} = \frac{\text{BOD}_{\text{in}} - \text{BOD}_{\text{out}}}{\text{BOD}_{\text{in}}} \times 100 = \frac{94.64 - 15.14}{94.64} \times 100 = 84.9\%$$

iii) BOD discharged per day:

$$\text{BOD}_{\text{out}} = 15.14 \text{ kg/day}$$

2023

$$\text{BOD}_{\text{ultimate}} = L_0 = 76\% \text{ of COD} = \frac{76}{100} \times 550 \text{ mg/L} \\ = 418 \text{ mg/L}$$

$K_2 = 0.23 \text{ per day}$

$\Theta = 1.043$

$$\therefore K_2 = 0.23 \times (1.043) = 0.3 \text{ per day}$$

~~$$\therefore K_2 = \frac{0.23 \times (1.043)}{0.239} = 0.24 \text{ per day}$$~~

$$\therefore \text{BOD}_3 = L_0 \left(1 - e^{-K_2 \times 3}\right) = 418 \times \left(1 - e^{-0.3 \times 3}\right) \\ = 253 \text{ mg/L}$$

2022

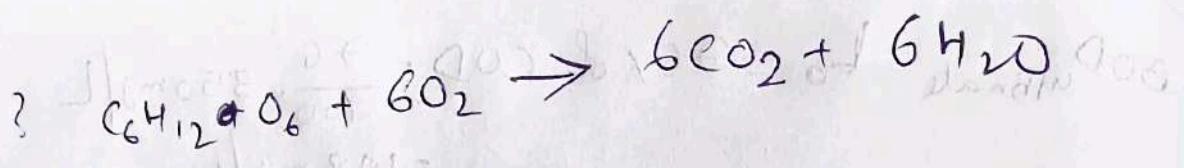
$$10^m 26.81 = 0.8 \times \frac{51}{58} = 0.7$$

?

$$10^m 10.50 = 0.8 \times \frac{51}{851} = 0.7$$

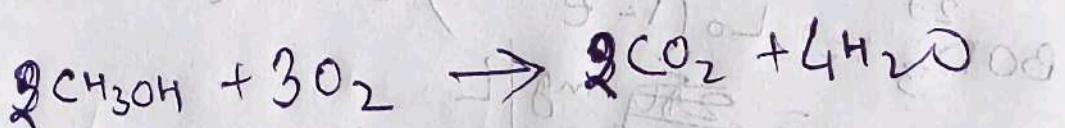
$$10^m Fd.181 = CF + fd.001 = 0.02 \text{ l/dt} = 0.1$$

$$0.1 - 0.2 \\ \phi \times 0.1^N = 0.2^N \\ \phi = \frac{0.2^N}{0.1^N} = (2N-1)^{-1}$$



$$\text{COD from glucose} = \frac{6 \times 32}{180} \times 100 = 106.67 \text{ mg/L}$$

$$\text{TOC} = \frac{6 \times 12}{180} \times 100 = 40 \text{ mg/L}$$



$$\text{COD} = \frac{3 \times 32}{2 \times 32} \times 50 = 75 \text{ mg/L}$$

$$\text{TOC} = \frac{12}{32} \times 50 = 18.75 \text{ mg/L}$$

$\text{C}_9\text{H}_{14}\text{O}$ : COD = 0

$$\text{TOC} = \frac{9 \times 12}{138} \times 80 = 62.61 \text{ mg/L}$$

$$L_0 = \text{Total COD} = 106.67 + 75 = 181.67 \text{ mg/L}$$

$$\therefore B_5 = L_0 \left(1 - e^{-K_{10} \cdot 5}\right) \quad \left| \begin{array}{l} K_{10} = 0.25 \\ \therefore K_{20} = K_{10} \times \phi^{20-10} \end{array} \right.$$