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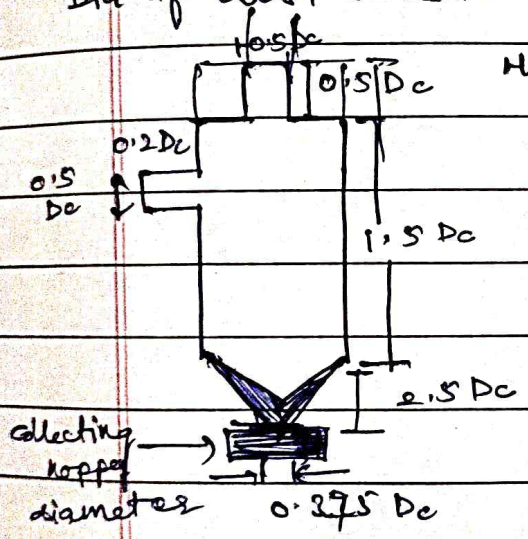
For high efficiency cyclone :- Q = 223 m³/hr
(HEC)
Dcyclone = 203 mm
Vinlet = 15 m/s.

The only difference is in input Q's

For high throughput cyclone :- Q = 669 m³/h
(HTC)
Dcyclone = 203 mm
Vinlet = 15 m/s.

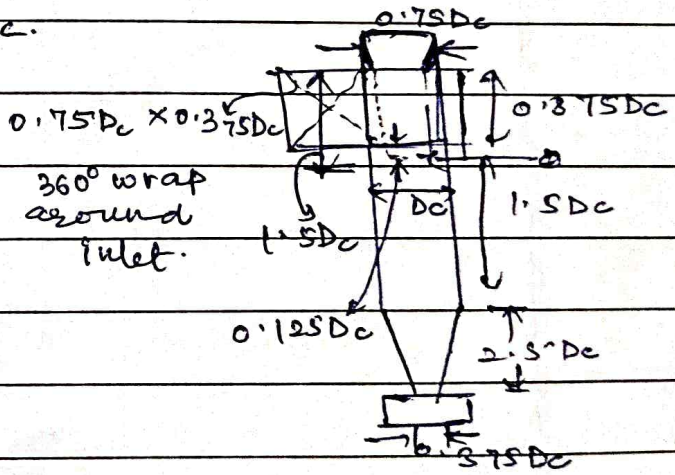
HEC → Dimensions

inlet duct area = b×h
b = 0.2 Dc
h = 0.5 Dc
Dia of exit gas pipe = 0.5 Dc
Depth of exit Tube = 0.5 Dc
Ht. of cyclone cylinder = 1.5 Dc
Dia of dust collector pipe = 3/8 Dc
Ht. of cone = 2.5 Dc.



HTC → Dimensions

inlet duct area = b×h
h = 0.75 Dc
b = 0.375 Dc
Dia of exit gas pipe = 0.75 Dc
Depth of exit Tube = 0.875 Dc
Ht. of cyclone cylinder = 1.5 Dc
Dia of dust collector pipe = 0.375 Dc
Ht. of cone = 2.5 Dc



$$D_{pc}^2 = \frac{9\mu_f b}{2\pi N V(\rho_p - \rho_g)}$$

D_{pc} = cutsize particle dia which will be collected with 50% efficiency

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

less than 50 we cannot use cyclone seperator

D_{pc} should be as smaller as possible to get the max. seperation by a cyclone seperator.

N = No. of turns particle is making inside the cyclone

V = vel. of ~~particle~~ air. (tangential air vel)

μ_f = vel. of gas (air)

$D_{p\,min}$ → particle dia collected with 100% efficiency.

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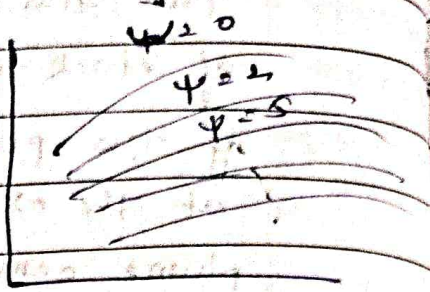
Pressure drop & cyclone seperator

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



ΔP = Pressure drop, millibar

ρ_f = Density of gas, kg/m³

u_1 = inlet duct vel., m/s

u_2 = outlet duct vel, m/s

r_t = radius of circle to which the gas centerline of the inlet, m

r_e = radius of exit pipe, m

ϕ = factor, $f(\psi, r_t/r_e)$

$\psi = f_c \cdot \frac{A_s}{A_1}$ f_c = friction factor

A_s = cyclone surface area

A_1 = area of inlet duct

Q = 223 or 669 m³/hr Q = 5000 m³/h.

high η high Q

ΔP should be within 10 psi.

Due to depos^n of dust particle at ↑ gas rate

ΔP may be more than 10 psi insufficient

Scale-up & cyclone design :-

223 for high efficiency

669 for high through

$$SF = \frac{d_2}{d_1} = \left[\left(\frac{DC_2}{DC_1}\right)^3 \times \left(\frac{Q_1}{Q_2}\right) \times \left(\frac{\Delta P_2}{\Delta P_1}\right) \times \left(\frac{\mu_2}{\mu_1}\right)\right]^{1/2}$$

SF → Scaleup factor

DC_2 → proposed dia of cyclone

DC_1 → actual dia

Q_2 → vol. flow rate = 5000

d_1 → mean dia. of particle at std. cond^n at the chosen sep^n efficiency or per high efficiency or height throughout cyclone.

d_2 → Mean particle dia. seperated in the proposed cyclone at same sep^n efficiency.

DC_1 = Dia of std. cyclone, 203 mm

DC_2 = Dia of proposed cyclone, mm

ΔP_1 = $P_P - P_f$ at std. cyclone, 5000 kg/m

ΔP_2 = $P_P - P_f$ for proposed cyclone

μ_1 = 0.85 cp

μ_2 = μ of gas of cyclone

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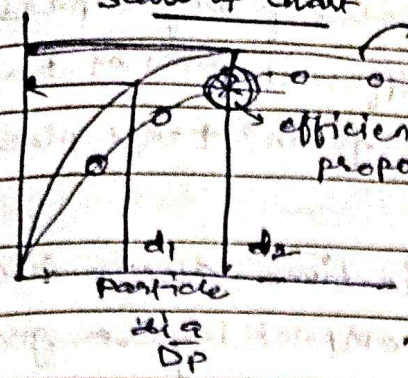
scale up chart



$b \times h \times v = Q$

$0.5 \times 0.2 \times v = Q$

Dc Dc

The efficiency of proposed cyclone is always lower than std. cyclone

$\eta_T = \Sigma \eta_i w_i$ → overall efficiency η_i → grade efficiency (for each dia particles)

Parameter	η		
Dust specific gravity ↑	↑	Vortex Finder depth ↑	↑↑
Air viscosity ↑	↓	b × h ↑	↓
Dust loading ↑	↑	Cylinder length ↑	↑
Inlet vel. ↑↑	↓	Cyclone dia ↑	↓
		Cone length ↑	↑
		Vortex finder dia ↑	↓

parameters are varied acc. to chart in order to ↑ cyclone efficiency

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cyclone grade efficiency

$$\eta_i = \frac{(D_p / D_{pc})^2}{1 + (D_p / D_{pc})^2} \times 100$$

D range	Dp	wt / wt %	η_i
0 - 5	2.5		η_1
5 - 20	12.5		η_2
20 - 50	35		η_3
50 - 100	75		⋮
> 200	⋮		⋮

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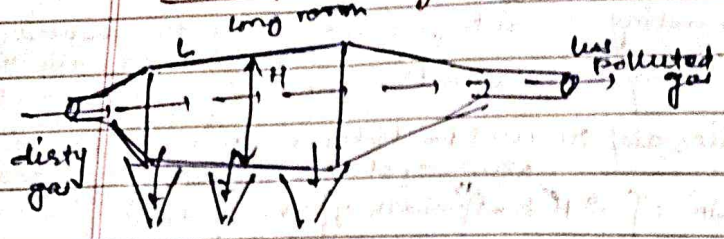
Gravity settling chambers :—

principle: gravitational attraction

Dia. of particles (D_p) > 50 μm

Laminal flow



Terminal settling vel of particles

$$u_t = \frac{D_p^2 (\rho_p - \rho_g) g}{18 \mu} \quad \text{(By stoke's Law)}$$

solid moves with vel. of gas along the chamber and settle with stoke's vel.

(ht. travelled before settling) $\frac{h}{u_t} = \frac{L}{V}$ (L: length of chamber, V: horizontal vel. of carrier gas) $\rightarrow$ $u_t = \frac{hV}{L}$

Dimensions of the room has to be very large (space occupying). ΔP is usually small (mainly entry & exit losses)

requires very low maintainence

efficiency ↑.

not effective for very high PM (~~charge~~) (particle size)

$h > H$ particle settles

$h < H$ particle not settles

vol. of the chamber = $W \times H \times L$

$$\eta = \frac{h}{H} = \frac{t \times u_t}{H} = \frac{L u_t}{VH} = \frac{u_t \times WL}{Q} \quad t = \frac{\text{Vol.}}{Q}$$

h = ht. travelled before settling.

$$D_{p,min} \Rightarrow D_{p,100} \left[\frac{18 \mu Q}{(\rho_p - \rho_g) g W L}\right]^{0.5} \quad D_{p,50} = \left[\frac{9 \mu Q}{(\rho_p - \rho_g) g W L}\right]^{0.5}$$

For turbulent region, $\eta = 1 - e^{-\frac{WLu_t}{Q}}$

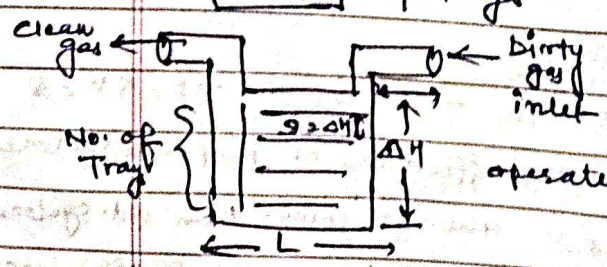
$$\% \eta = \left(\frac{D_p}{D_{p\,min}}\right)^2 \times 100\%$$

* H : W : L = 1 : 2 : 3 ∴ $\Sigma \eta_i w_i \rightarrow$ overall efficiency of the chamber

Multitray settling chambers :—

$s = \Delta H \rightarrow$ b/w trays

$$D_{p,min} = \left[\frac{18 \mu Q}{(\rho_p - \rho_g) g W L} \times \frac{s}{H}\right]^{0.5}$$

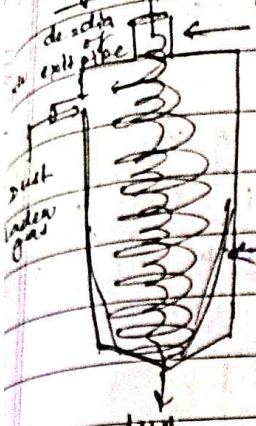


$\Delta H = (40 - 50)$ cm

operated as preliminary dedusting if dia > 50 μm.

$$D_{pc}^2 = \frac{9\mu B}{2\pi N V(\rho_p - \rho_g)}$$ 50% efficiency

Cyclone seperators :- 2 parts → cylindrical + conical



forces acting → centrifugal → drive the suspended particles to the wall

higher dia / bigger particles → go to edge (periphery of the walls)

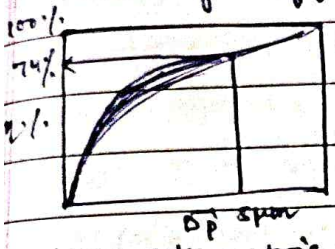
smaller dia / smaller particles → go to center of the cylindrical and cone part.

$$D_{p,min} = \left[\frac{9\mu B}{2\pi V N_e(\rho_p - \rho_g)}\right]$$

μ → viscosity of air; B → width of the cyclone inlet duct; $D_{p,min}$ → smallest particle that can be removed; N_e → No. of turns made by gas stream in cyclone; V → avg. inlet vel. (tangential)

2 types of cyclone based on efficiency

High Efficiency Cyclone

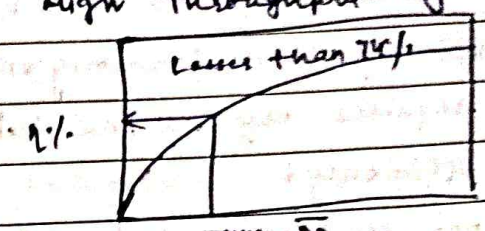


Low volumetric flow rate

$Q = 223\ m^3/hr$ $D_{cyclone} = 203\ mm$

$v_{inlet} = 15\ m/s$

High Throughput cyclone



High volumetric flow rate

$Q = 669\ m^3/h$ $D_{cyclone} = 203\ mm$

$v_{inlet} = 15\ m/s$

Pr. drop & cyclone seperator :-

$$\Delta P = \rho_f \left[\frac{K_1^2}{2}\left\{1 + \frac{2\psi^2}{f(\psi, r_t/r_c)}\left(\frac{r_t}{r_c} - 1\right)\right\} + 2u_2^2\right]$$

ρ_f → density of gas; r_t → radius of circle to which gas centerline of the inlet; u_2 → outer duct vel.; $\psi = f_c A_s$ (f_c → friction factor, A_s → cyclone surf. area); A_i → area of inlet duct

ΔP must be below 10 psi. However due to deposn of dust particles at ↑ gas rates. ΔP may be more than 10 psi

Scale up & cyclone design :-

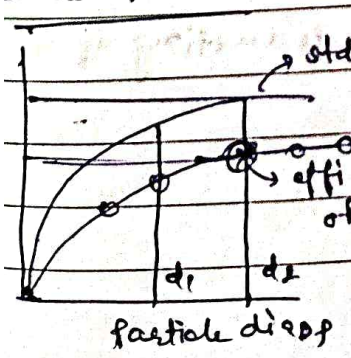
$$SF = \frac{d_2}{d_1}\left[\left(\frac{D_{c2}}{D_{c1}}\right)^3 \times \left(\frac{Q_1}{Q_2}\right) \times \left(\frac{\Delta P_2}{\Delta P_1}\right) \times \left(\frac{\mu_2}{\mu_1}\right)\right]^{1/2}$$

d_2 → mean particle dia seperated in the proposed cyclone at the same eff.

D_{c2} → dia of proposed cyclone

$D \times h \times V = Q$ → $0.5D_c \times 0.2D_c \times V = Q$

Scale up chart :-



The efficiency of proposed cyclone is always lower than std. cyclone

$\eta_T = \Sigma \eta_i w_i$ → overall efficiency

η_i = grade efficiency (for each particle)

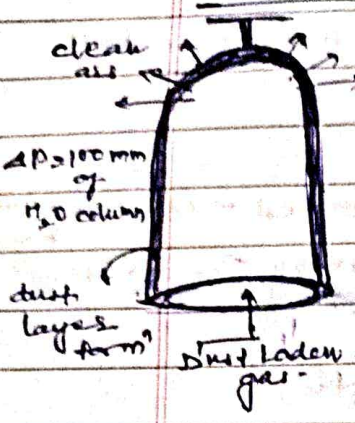
Cyclone grade efficiency

$$\eta_i = \frac{(D_p/D_{pc})^2}{1 + (D_p/D_{pc})^2} \times 100$$

Parameters :-

Dust specific gravity ↑	↑	Vortex finder depth ↑	↑	vortex finder dia ↑	↓
gas vel ↑	↓	b × h ↑	↓		
Dust loading ↑	↑	cylinder length ↑	↑		
inlet vel. ↑↑	↓	Cyclone dia ↑	↓		
		cone length ↑	↑		

Fabric filters (Bag houses) → excellent fine particle removers



- surface area of bag expands
- → Through different pores of bag pure air flows out
- Dust Layer form^n takes place inside bag filter
- after certain time, due to deposition of particles - compact layer gives additional resistance to particle flow and efficiency of the bag filter ↑ with time from begin^n
- inside pores of filter media - dust accumulation.

- only case where efficiency ↑ with time
- In industries a cage like structure supports bag filter
- dust laden gas comes from outside in industry and cleaning of filter is easier this way.
- T_{max} for bag filter = 80°c cannot use bag filter if T > 280°c
- used for T ~ RT to 100°c
- different filter media used - cotton polymers, glass fiber

How to select different filter media (acidic/alkaline) at diff T's
(gas T) (gas composition) gas flow rate size & shape of dust par

Types of bag filter
- air cooled bag filter
- water cooled bag filter
- pleated bag filter → dust gets accumulated on the pleats

issues :- ① air to cloth ratio → $SA = \pi DL + \pi r^2$

② if > 2.5 → The pores on the clothes will try to expand and there will be rupture or breaking of threads → hole form^n → all the gases try to flow out → all dust will escape → no control of emission → ΔPd and emissions shoot.

③ if ΔP drops in bag filter → rupture in bag
→ no gas inflow

④ in rainy season → moisture entering → makes the hygroscopic material wet → clay like form^n on the walls → leads to clogging of
will have to replace the bags

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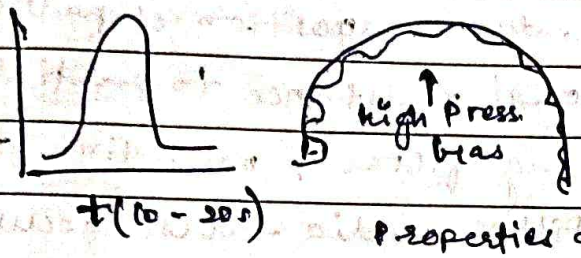
Cleaning bag filter :-

Shaker type → mechanical vibrn → shaking → dust particles fall.
reverse jet bag → high P gas flows in reverse dirn
Pulse jet bag → high pressure gas flows



compressed air passed → expn & vibrn of bag
pulse for 10 - 20s in every 30s interval

Properties of some fibers material (Pic)

For pleated bag filter the surf. area is 3 - 4 times more than normal bag filters → cake formn in b/w the pleats if humidity ↑ / cleaning not proper.

Bag filter opn :-

→ const. capacity t = 0 Q = Q1 → to overcome ΔP loss with time → Q (rel. flowrate of air) remains const
→ const pressure t = t Q = Q.

valve opened slowly to ↑ flow of gas
① KE of gas overcomes ΔP loss
② const. rate bag filter
↓
③ controls flow rate.

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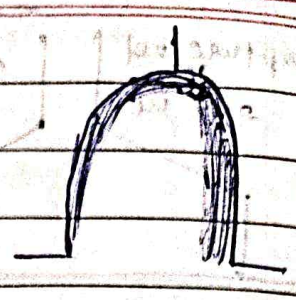
Design of Bag filters :-



Total surface area = N × As

$A_s = \pi DL + \pi R^2$

Air to cloth ratio = $\frac{Q}{N \times A_s}$ (m/s)

polymeric (nylon) → higher air to cloth ratio → Low change of rupture

(0.5 to 4) → glass fibre (Low) (2.5 or less than 2.5) → fine powder like material

→ elastic material where filter media can expand (high)

if the baghouse has :-

→ Low cloth ratio → more bag filters

→ high cloth ratio → less bag filters

→ const. capacity bag filter

→ const. ps bag filter

Filter vol. $v = \frac{Q_a}{A_s}$ = $\frac{\text{actual } m^3 \text{ of gas per hour}}{\text{surface area, } m^2}$

Opern of Bag filters :-

$t_f + t_c$ = Total opn time

t_f → time of filtrn, t_c → time of cleaning

max. capacity : $Q = \frac{\text{vol. of gas filtered}}{t_f + t_c}$ (time of opn)

at $t_c = 0$

$Q_{max} = \frac{\text{vol.}}{t_f}$

$Q_{optimum} = \frac{\text{vol.}}{t_f + t_c}$

(for optimum opn of plant)

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$Q \Rightarrow 3000\ m^3/hr \Rightarrow 20000\ m^3/hr \Rightarrow 200000\ m^3/hr$

$\Rightarrow 5000\ m^3/hr \Rightarrow 40000\ m^3/hr$

$\Rightarrow 10000\ m^3/hr \Rightarrow 100000\ m^3/hr$

* smaller capacity bag filters preferred in plants due to ease of op^n (cleaning / maintanence / replacement)

<u>filtr^n Time:</u>

$\Rightarrow$ For const pressure operation

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

ΔP → Pr. drop; v_g → vel. of the gas filtered

→ cotton → ΔP more

→ polymeric → ΔP less

→ glass fibre → ΔP further less

ΔP depends on permeability

If resistance of the bag is negligible

$$t_f = \left(\frac{B}{2\Delta P}\right) v_{cl}^2 \qquad B = \frac{\mu_G C}{\rho_B K}\left(\frac{1}{A^2}\right)$$

$$\boxed{t_f = K^* \times \frac{V_{cl}^2}{A^2}}$$

$$Q = \frac{Vol.\ (V_{cl})}{t_f + t_c}$$

C = cunningham correct^n factor

ρ_B = Bulk density of filter cake

K = permeability coeff

A = A_s = Area.

airbag → roof to bottom → 10 to 10.5 ft → (3 to 4) m.

bag filter dia → 30 cm

No. of bags can be found out.

$$N = \frac{A_s\ (\text{Total surface area available})}{\text{Area of std. bag}}$$

No. of bag filters ↑↑ → compartments created

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filter area (m^2)	No. of compartments
1 – 200	1 – 2
1001 – 1600	8 – 10
3001 – 4100	17 – 20

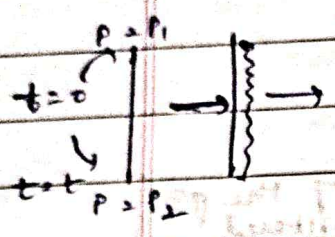
more compartments require more maintenance

Const capacity Bag filter :–

$\Delta P = BQ^2 t + CQ$ $\quad$ Q = volumetric flow rate of gas

t = time

B & C are constants

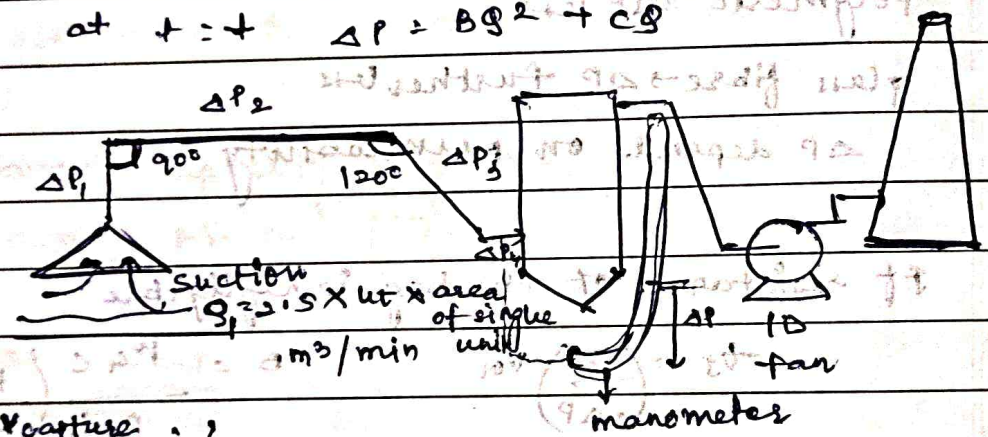


to p.p.s. ↓ we use compressor

$P_2 > P_1$ to maintain const. capacity

at $t = 0$ $\quad \Delta P = CQ$

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



Vcapture = ?

$\Delta P = \Delta P_1 + \Delta P_2 + \Delta P_3 + \cdots$ → Total ΔP loss (% loss)

Total capacity$_1$ = $Q_1 + Q_2$ (Bco2 of ΔP)

Total load on ID fan to be calculated.

$$\eta = \frac{C_1 - C_0}{C_0} \times 100$$

Q. An old filter from a discontinued process is to be utilized for const. pr filtrn at 12.7 cm of water. The filter has 20 bags of 7432.84 cm^2 each. Cleaning time is det. as 45 min for the given pr filtrn the eqn. is,

$t = 674.82\, V_G^2$ where t is time in min

V_G = Vol. of gas filtered / unit area ($\frac{m^3}{cm^2}$)

Max. overall capacity.

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Calc the capacity of this filter under given condn

overall capacity = $\frac{V_G}{t_f + t_c}$

t_c = 45 min.

A = N×Ai

Total area = 20 × 7432.24

= 14.86 m²

for max capacity t_c = 0

t_f = 674.82 V_G^2

$V_G = \left(\frac{45 \text{ min}}{674.82}\right)^{1/2}$

for optimum opⁿ $\boxed{t_f = t_c}$

V_G = 0.258 m³/cm²

Total gas vol. = $\frac{0.258}{10^{-4}}$ × Total area (14.86)

= 38338 m³

$Q_{max} = \frac{V}{t_f}$ = $\frac{38338}{45 \times 60}$ =

$Q_{opt} = \frac{V}{(t_f + t_c)}$

Q A filter is operating at const. rate on an optimum cycle.

$V_G^2 = 2.623 \times 10^6 t \times P^{0.65}$ ← filtrⁿ eqⁿ.

P → cm of H_2O

V_G → m³ of gas

t = time, min.

The filtrⁿ time is 45 min and cleaning time is zero

ΔP is 10.16 cm of water. (1) Calc. overall capacity.

(2) It is necessary to ↑ the capacity of the filter. It has been suggested that an additional unit of identical capacity to the present one be installed. Both units ~~with~~ would work from the same ID fan which has ample and filtrⁿ would be carried out to the same max. pr. as at present one. The time reqd. to shake and clean 2 units is estimated as 4 min what is the max % ↑ in overall capacity that could be

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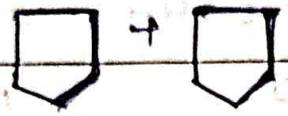
achieved by adopting this suggestion?

In second case → $V' = 2V$ → initial vol. × 2.

$Q_1 =$

$Q_2 =$ 

$V_a^2 = 2.623 \times 10^6 \, t \times p^{0.65}$

→ $V_a = 23080.4$

$Q_{max} = \frac{V_a}{t_f} = \frac{23080.4 \times 60}{45}$

$= 30773.86$

$Q_2 = \frac{2 \times V_a}{t_c + t_f}$

t_c → 45 min, t_f → 4 min

$Q_2 = \frac{(2 \times 23080.4) \times 60}{49}$

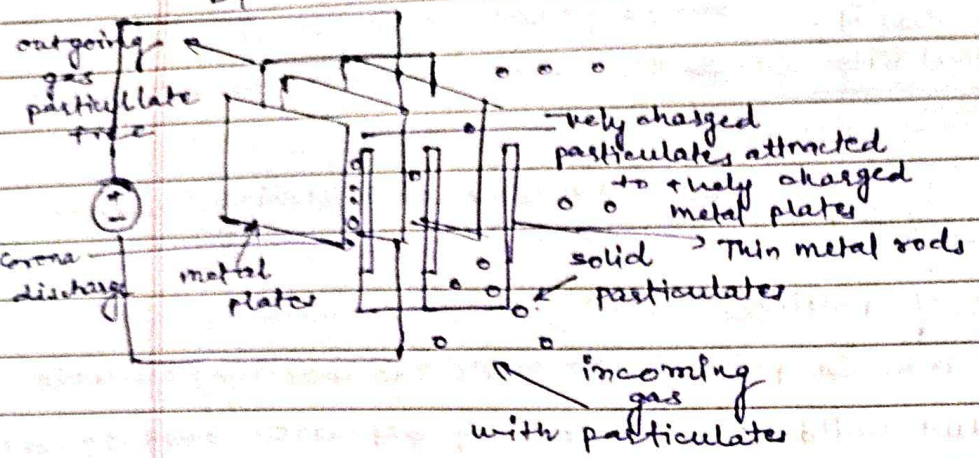
$= 56522.44$

$\% \uparrow = \frac{Q_2 - Q_1}{Q_1} \times 100$

$= 84\%$

ESP :- Electrostatic precipitator :- → used for vv fine particles at very high Temp.

$\overline{D_p}$ = 0.1 to 20 μm $\vec{E}$ (Electric field) = 60 000 to 90000 V



Principle

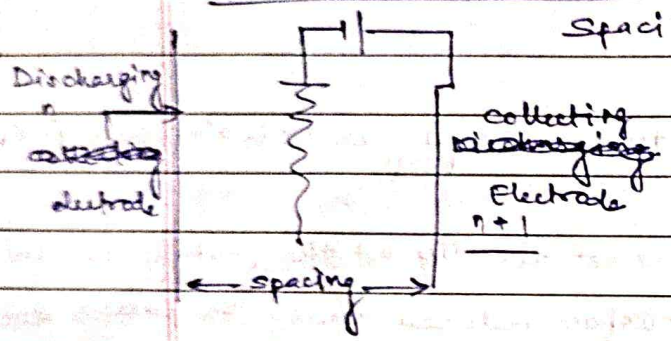
charged particulates are attracted to collector plates carrying the opposite charge

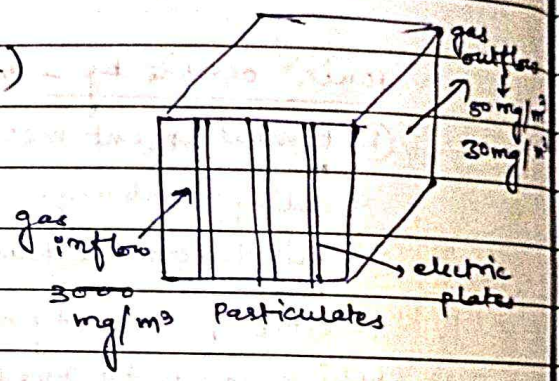
dielectric properties of fly ash determines efficiency

$\eta = 99.99\%$

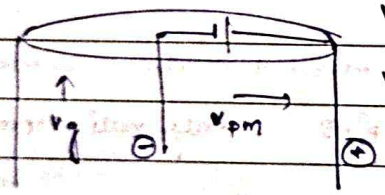
① Plate to plate (parallel plate) type ESP

Spacing → 20 - 30 cm (industrial)





② Wire in cylinder type :-

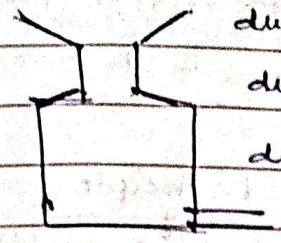


v_g → vel. at which gas moves through ESP

v_{pm} → particle migration vel. → vel. at which ionised particle moves towards collecting electrode

Working of ESP :- The gas stream is passed b/w 2 electrodes, across which a high potential difference is maintained. one is a discharging electrode and other is a collecting electrode. Bcoz of the high ΔV (p.d.) and the discharge system, a powerful ionizing field is formed. Ionizn creates an active glow zone (blue electric discharge) called the 'corona or corona glow'. As the particulates in the carrier gas pass through the field they get charged and migrate to the oppositely charged collecting electrode, gets deposited and lose their charge. They are either removed mechanically by rapping, vibrn or washing.

Height ↑ → ↑ Performance



dust hoppers
↓
dust storage containers
dust sent to dust silos

if plates get bent due to thermal shock gap b/w plates → decreases ~~due to which~~ corona / channelling of dust particles So the plates need to be discarded.

→ dust buildup on collecting surface

Steps :- ① ionizⁿ of particles.
② movement of ionized particles towards the collecting electrode
③ deposition of dust build up → collectⁿ of deposited dust to hopper

$e^{\ominus}$ → o dust particle.

Ionizⁿ occurs by 2 mechanism :-
(i) bombardment mechanism :- $e^{\ominus}$ from discharging electrode hits dust particle leading to charge transfer
(ii) diffusion mechanism – $e^{\ominus}$ does not directly hit the particle, but due to close proximity of $e^{\ominus}$ there is surface induced charge on particle ~~due~~ which leads to surface charge on other particles too.

$\boxed{\text{Critical electric voltage}}$ needs to be applied for above 2 mechanism to appear

$(qt)_b = ne = 0.19 \times 10^{-9}\, r_p^2 \cdot E$ only valid for $\epsilon = 2.5$ (dielectric)

n → no. of electronic charge.

$e^{\ominus}$ → o → e → electronic charge $= 1.6 \times 10^{-19}$ C

r_p → radius of particle

E → Avg. field intensity : V/m

$$(qt)_b = (qt)_{b,\epsilon=2.5} \left[\frac{DB=2}{D\epsilon=2.5}\right]$$

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

for diffusional :- $(qt)_d = ne = 2 \times 10^8\, r_p e$.

$$qt = (qt)_b + (qt)_d.$$

for very fine particles where ESP cannot capture flue gas conditioning is done

$SO_2 + NH_3 + H_2O \longrightarrow (NH_4)_2SO_3$ or $(NH_4)_2SO_4$.

Flue gas contains SO_2, NH_3, in flue gas conditioning, H_2O is passed through the flue gas to form ammonium sulfate.

The $(NH_4)_2SO_4$ formed deposits on the dust particle which leads to other dust particles to stick to this particle leading to a form of dust particles (from finer to larger particles) → easily captured by ESP.

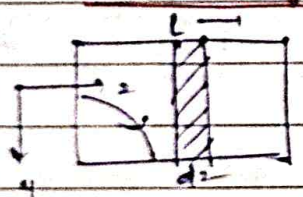
As $(NH_4)_2SO_4$ sticks to dust, ε changes

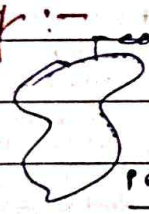
$$\boxed{V_{pm} = \frac{q_{st} E c}{3\pi \mu d_p}}$$

c = cunningham correcⁿ factor, E = Electric field, μ = viscosity, d_p = particle dia (μm)

$V_{pm} \simeq 0.14$ to 0.18 m/s.

ESP collecⁿ efficiency :-





collecting surface area = A

perimeter = P

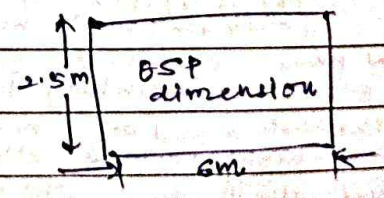
V_p → z gas vel.

V_{pm} → particle migration velocity.

Inlet = outlet + dust collected on the surface

in − out = collected.

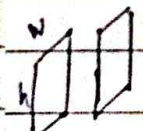
$A \cdot V(\Delta C) = V_{pm} \times P \times dz \times C$



$\Rightarrow m^2 \times \frac{m}{s} \times \frac{kg}{m^3} = \frac{m}{s} \times m \times m \times \frac{kg}{m^3}$

$\Rightarrow kg/s = kg/s$

$$\Rightarrow -\int_{C_0}^{C_L} \frac{dC}{C} = \frac{V_{pm}}{V} \times \frac{P}{A} \int_0^L dz \Rightarrow \frac{C_L}{C_0} = \exp\left(\frac{V_{pm} P L}{VA}\right)$$



A = 2 × w × h
↓
collecting electrodes

$$\Rightarrow \eta = \frac{C_0 - C_L}{C_0} \times 100 = 1 - e^{-(V_{pm} A_c / Q)}$$

$$\rightarrow \eta = \frac{C_{inlet} - C_{outlet}}{C_{inlet}} = 1 - \exp\left(-\frac{V_{pm} A_c}{Q}\right)$$

E = V/m
↓
Avg. Electric field Intensity

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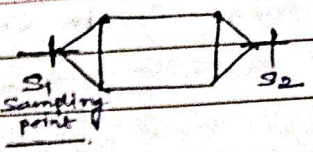
$\overline{d_p} \leftrightarrow \overline{V_{pm}}$ 2019 & before → discharge limit

mapping 100 mg/m³ or 50 mg/m³

after 2019 → 30 mg/m³



$$\eta = \frac{C_0 - C_f}{C_0} \times 100\%$$ → should come more than 99.9%.

If $\eta = 0.01\%$ → change ESP plate, electrode or alter spacing.

Wet Scrubbers :—

a.) particulate matter } (a+b) or (b)
b.) gaseous emission

generally not used for only PM → CO_2
PM are extremely fine particle & when mixed with the solvent they become very difficult to manage and cause water pollution.

gaseous pollutants →

adsorption	absorption	condensation	combustion
interⁿ b/w gaseous contaminants (adsorbate) and the surface of a solid adsorbent → the pellets in a thick bed, small beads in a fluidized bed, fibers pressed on a flat surface. types → physisorption, chemisorption (chemical rxⁿ)	transfer of a gaseous comp. from gas phase to liq. phase performing factors → liq. surf. area available for MT and the time available for the diffusion of the gaseous molecules	systems are used exclusively for recovery of organic compds. present at moderate-to-high conc^s in industrial process effluent gas streams. Condensⁿ sys : conventional refrigeration, cryogenic. Refrigeration and cryogenic used primarily for high efficiency recovery of high-value contaminants	Lot of carbon vapours adsorbed gas can be sent to combustion chamber (calorific value is utilised) coke oven gas
Vapour phase compounds in the gas stream (adsorbate) pass through a bed or layer of highly porous material called the adsorbent.	gaseous contaminant being absorbed must be atleast slightly soluble in the scrubbing liquid, termed the absorbent. MT continues until liq. approaches saturⁿ. At saturⁿ, eqlbm. is established b/w the mass transfer rate of the contaminant to the liq. and mass transfer rate of dissolved species back into gas phase	conventional sys. (direct contact condenser, surface condensers) coolant & vapor stream are physically mixed. coolant is seperated from the vapors by tubular heat transfer surfaces. shell & tube heat exchangers	

Imp. – Internal porosity, Surface area, Pore volume, Bulk density, Mean pore diameter.

types of adsorpⁿ sys. → regenerative adsorpⁿ systems, non-regenerative adsorpⁿ systems

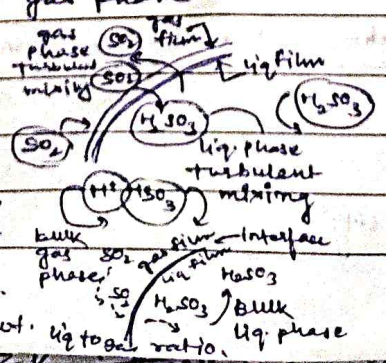
Isotherm → plot of adsorbent capacity v/s the partial ps. of adsorbate at const. T

for const. T adsorpⁿ capacity ↑ as partial ps. ↑

used to estimate the size of adsorpⁿ systems

breakthrough capacity → capacity of the bed at which unreacted vapor begins to be emitted.

Saturation Capacity → max. amt. of vap that can be adsorbed per unit wt. of C



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Wet scrubbers :—

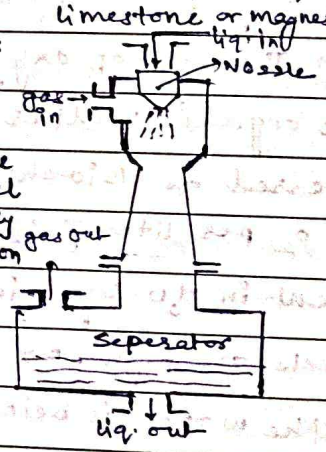
- transfer pollutants from air to water
- further treatment may be necessary
- pollutants must be highly soluble in water
- for less soluble materials, a chemical may be added to water.
- SO_2 may be removed by reacting with limestone in H_2O.
- $SO_2 + CaCO_3 \rightarrow CaSO_4 + CO_2$

$CaSO_4$ crystals are removed from scrubber as a solid.

Advantages	Disadvantages
- handle flammable & explosive dust	- high corrosion potential
- gas absorption and dust collection	- ~~gas absorption and dust collection~~
- handle mists	- liq waste stream
- cooling of hot gases	- freezing protection needed
- handle corrosive gases & dust.	- no recycling of particles

Wet collectors :—

Spray towers	Packed beds	Bubble or plate towers	Venturi scrubbers	Cyclonic scrubbers	Miscellaneous scrubbers
liq. can be sprayed into a gas stream by means of a nozzle which disperses the liq. into a fine spray of drops. The flow may be counter current, as in vertical towers with liq. sprayed downward, or parallel as in horizontal spray chambers. Adv. of low pr drop for the gas. Disadv., relatively high pumping cost for the liq., owing to the pr. drop through the spray nozzle. Unless the dia. length ratio is very small. gas will be fairly thoroughly mixed by the spray and full adv. of counter current flow cannot be taken	used for cont contact of liq. & gas in both counter current & concurrent flow, are vertical columns filled with packings or devices of large surface. The liq. is distributed over, and trickles down through the packed bed exposing large surface area to contact the gas.	continuous absorbing liq., from bottom, gas is bubbled surface renewal breaking of bubbles to form smaller molecules air jet impinges upon the above each plate hole removal predominantly by impaction	for liq. containing suspended solids similar to ejectors gas is drawn into the throat of a venturi by a stream of absorbing liq. sprayed into the convergent duct section in absorpn of SO_2 from furnace gases with slurries of lime, limestone or magnesia	water is sprayed in high speed in a cyclonic manner ↓ gas pollutants or very low conc pm containing gas. agitator used to form bubbles.	



Assignment → Design a wet scrubber to handle a contaminated gas which contains SO_2 at 10 ppm level. $Q = 140000\ m^3/hr$ at a $T = 80°C$. Exit conc of $SO_2 = 0.1$ ppm.

Wastewater Treatment :—

① pH (6.5 to 8.0) → depends on the sro. of its gen^n acc. to that it varies (for freshwater) Extremes of pH may adversely effect aquatic ecology in surface water bodies. range of pH suitable for fisheries is considered to be 5.0 – 9.0, though 6.5 – 8.5 is preferable.

Acidity of H_2O is generally attributed to carbonate molecules H_2CO_3 and HCO_3^- and sometimes to strong acids releasing H^+. Alkalinity is a fn of carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) and hydroxides (OH^-) content of water. more acidic carbonate molecules in sol^n (H_2CO_3, HCO_3^-, H^+) pH <7

More HCO_3^-, CO_3^{2-}, OH^-, pH >7 (basic)

② BOD (Biological Oxygen Demand) :—

DO (Dissolved O_2) :— Natural stream purific^n processes req. adequate O_2 levels in order to provide for aerobic life forms. As DO levels in H_2O drop below 4.0 mg/l, aquatic life is put under stress. DO levels below 1–2 mg/L for a few hrs may result in large fish kills.

BOD → BOD_5^{20} → The amt. of oxygen required by aerobic microorganisms to decompose the organic matter in a water sample (generally polluted) is typically referred as Biochemical Oxygen Demand or Biological (OD)

BOD_5^{20} → mg of O_2 per liter of H_2O reqd. to completely degrade the organic matter present in H_2O by microbes at a T of 20°C for 5 days time (BOD_5^{20})

When BOD levels are high, DO levels decrease because the oxygen that is available in the water is being consumed by the bacteria. If the quantity of organic waste present is sufficiently large, the rate of bacterial uptake of oxygen will outstrip that at which the DO is replenished, and ultimately the receiving water will become anoxic / anaerobic

Ultimate BOD :— if ∞ days given then entire degradation occurs.

aerated water find how much mg O_2 consumed by microbes in 5 days.

③ Chemical oxygen Demand (COD) :— measure of organic materials in a wastewater in terms of the O_2 reqd. to oxidise the organic materials chemically. COD is measured as a standardized lab. assay in which a closed water sample is incubated with a strong chemical oxidant, $K_2Cr_2O_7$ (potassium dichromate) which is used in comb^n with boiling H_2SO_4.

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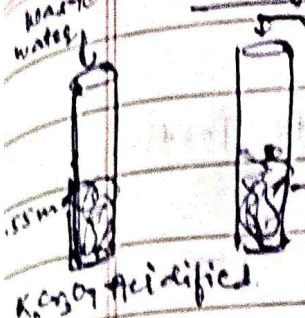
COD Digestors → known chemicals



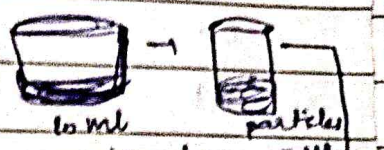
→ $K_2Cr_2O_7$

get lank absorbance

measure absorbance

compares absorbance to get an idea of how much COD.

TSS → Total suspended solids



find differences in wt.

~ 96 hours time to settle.

settlable portion

we get remaining water.

Take 1 glass / bottle of water (W1)

↓ 96 hours

Filter out water

after filtering our on the filter paper solids deposited

↓

air oven to evaporate water

Take wt. of the solid residues = mg/L

100 ml of H_2O → W_1

↓ 96 hours

W_2 + Evaporated Solids (in filter paper)

TSS = mg/L.

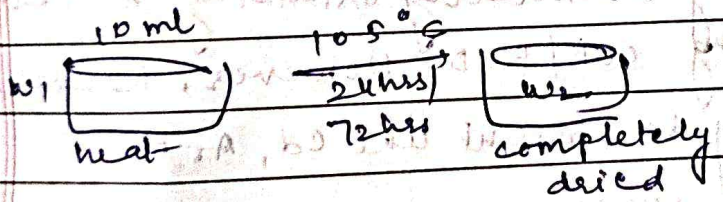
TDS → Total dissolved solid.

the filtered H_2O contains dissolved solids

take 10 ml H_2O (filtrate) → petri dish (105°C, 24 hrs) or 72 hr → wt of solids

$\frac{W_2 - W_1}{10\ ml} = mg/L$

W_1 → wt of empty glass container



Salinity :- Measure of diff types of salts : Na/Mg chlorides

conductivity of wastewater changes

more ions present (if salinity ↑)

Heavy metals :- Cd, Cr, Pb, Zn, As, fluorides → ionometer (ion exchange resins)

↓ flame → furnace mode

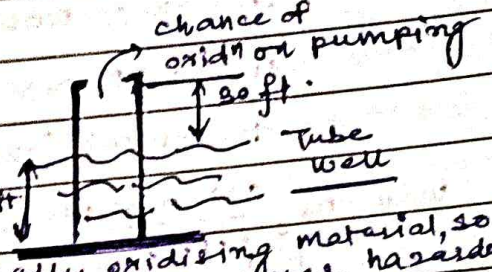
→ atomic absorption spectrometer used to detect

→ sophisticated analytical measurements used.

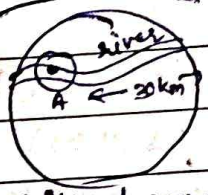
Collection of water sample :-

onsite testing ↔ offsite testing

(A) → Characteristics → DO, pH, Turbidity, Salinity, Solids, BOD & COD, Heavy metals, nitrides, phosphides, chlorides



Surface Water	Underground Water
river / lake / pond / canal or industrial discharge	Tubewell.
In case of riverwater ponds etc there takes place surface activities such as bathing, washing, movement of fish we dont collect samples from such areas as local water pH differs	No biologically / chemically oxidising material, so no. use of finding COD / BOD. However, hazardous metals may be present like Cd, As etc.
Collect activities from pond where no human activities are taking place → 3 different samples of pond / riverwater at 3 different locns (10 – 20 m away)	Collect 30 ml by pumping on spot → 2-3 drops nitric acid (immediate acidificn) → completely oxidized → then conduct lab tests



(A) sample pt. → collect sample within 500 m radius → mix all these samples in glass / poly acrylic type containers / jars and conduct testing / expts.

Keep 500 ml of water in ~~distl~~ chilled condn in lab (TH) to stop any biological activity

Water is discharged in 2 ways → effluents released directly from plant into waterbodies (conc wastewater without treatment)

↓

released in ponds & other waterbodies after some treatment

Industrial discharge → (A) CPCB checking regarding standards.
→ (B) Reuse / Recycle the water to plant → for any sec treatment done in the plant

Tubewell water needs to be checked for Ecoli testing. → Do not put nitric acid (ecoli will be killed)

Ecoli reaches household even after water treatment because public water distribn syst consists of overhead storage tanks (used by Municipality) where water is pumped from nearby ponds, rivers, water bodies which is generally dirty water & contaminated which gets percolated in pipes Thus passing Ecoli to the distribution system. In pipelines there is scale formn with time where these bacteria thrive & contaminate water

$\frac{COD}{BOD}$ def^n → $\frac{\text{mg of } O_2 \text{ req.}}{\text{ltr.}}$ → Quantifiable

$\frac{COD}{BOD} \geq 1$ or > 0.7 → BOD content of water high
- if v high → BOD treatment not suggested as COD is very high
- if low, do biological treatment

$\frac{BOD + \text{Excluding } BOD, O_2}{BOD}$

$\frac{BOD}{COD} \approx 1$ → secondary or biological treatment

$\frac{BOD}{COD}$ → very less → tertiary treatment

Composition of Wastewater
- Industrial wastewater (industries → BOD/COD may be v high) Loading is high
- Domestic Wastewater (comes from Municipality)

There are different disposal issues with Tertiary processes.

① Zero discharge → all the discharged water needs to be reused i.e they can be discharged anywhere. Some places it poses a very difficult problem to achieve zero discharge. if BOD content high, but water quality good then recycling easy but not complete recycle possible.

② sludge materials disposal. – They can be used as biofertilizers. In the integrated wastewater treatment plants, sometimes we can use anaerobic degradation (CH_4, CO_2), we can seperate Methane for other uses (TPP & fertilizer industry)

Water is precious so amt of water that can be used in plants needs to be restricted. The wastewater bacteria can be used to trap CO_2 & CH_4 (fuel)

Screening

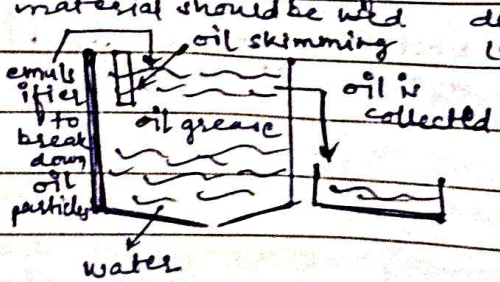
Screen → a device with openings, gen. of uniform size used to retain suspended or floating coarse materials (wood, pieces of clothes, rag etc that could damage subsequent process equipment

Municipality waste water contains variety of materials which needs to be skimmed completely.

Primary Treatment

(sand, stone, dust removal only removes a part of BOD/COD) → grit removal is necessary

- for wastewater treatment, no costly material should be used



Sec. Treatment

organic matter removal is targetted

Biological treatment processes rely on the ability of micro organism to decompose the soluble (and suspended) organic matter

Tertiary Treatment

(heavy metal, metallic salts) used only for specific type of contaminant

Ferrous alum is used instead of polyalum because it is cheaper

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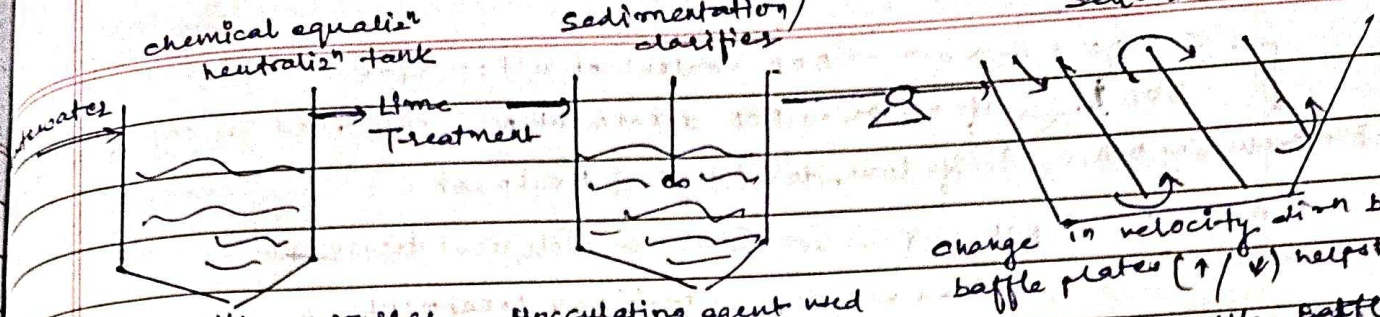
chemical equalizn neutralizn tank

Sedimentation / clarifier

Settler



Water from different sources or to the equalizn tank grit sepn etc. have been done. To balance fluctuating flows or concn, assist self neutralizn, to even out the effect of a periodic "slug" discharge from a batch process. Sometimes equalizn tank can be attached with different units.

flocculating agent used $Al_2O_3 \cdot H_2O \rightarrow Al(OH)_3$ settling

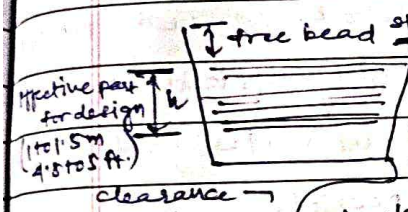
overall BOD/COD load will ↓ by 35% bcoz organic substances also settle at the bottom

change in velocity dirn b/w baffle plates (↑/↓) helps the substances settle. Baffle plates ↑ the residence time of the liq. being process by creating a longer path for the liq. to follow, the settling process can occur more effectively.

Design of primary settler tank :-

$Q = V \times A$

Retention time = $\frac{\text{length}}{\text{Settling vel.}}$

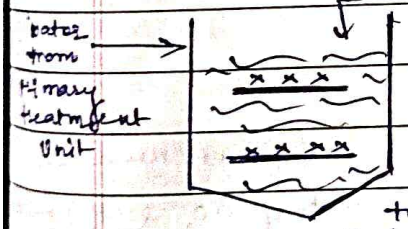


2 vels. → settling vel. of particle
→ vel. of water

at the bottom of the tank we need to give some clearance

Secondary treatment :-

Aeration Tank

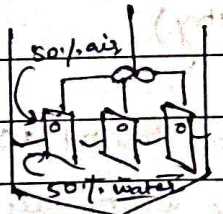


Nutrients (Phosphates N_2, Urea) fertilizers feed material to grow microbes

to consumed the BOD in our wastewater

microorganisms metabolize organic material converting it into CO_2 or other gases

or



impeller sets for O_2 supply

vertical mixing

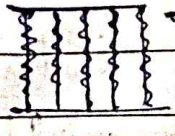
Aerated lagoons → uses large shallow basin for wastewater treatment. Relies of natural assimilatn capacity of the environment and microbes present in the lagoon.

Lagoon is either aerated by mechanical means or natural aeration due to wind & water movement

There are anaerobic lagoons which operate without O_2 - use anaerobic bacteria to break down organic matter in the absence of O_2 used for wastewater with a high conc of organic material

Acclimatization → diluting conc of wastewater to prevent dying of bacteria. Slowly low load to high load for adapting the bacteria.

Trickling filter → aerobic treatment process consists of a bed of media (rocks or plastic media) through which wastewater is distributed as thin films or trickles. Microorganisms including aerobic bacteria, colonize the media surface and break down organic matter through aerobic processes



→ Immobilized culture of microbes

air is passed from bottom & water collects

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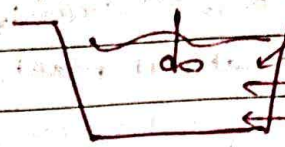
Tertiary Treatment :-

Semi fluidised bed reactor - combines the characteristics of fluidised bed reactor and fixed film reactor particles with density ≈ 1 kg/m³, solid media to provide surface for microbial attachment & growth. The bed is fluidised intermittently by periodically injecting air to other gases into the reactor, causing the media to become partially suspended.



For primary treatment method :-

flocculating agents are of different types. These are added to facilitate aggregation of fine particles and colloidal matter, making it easier to separate them from the water. These agglomerates settle down. When settle → bleaches BOD of wastewater ↓.

In Sewage wastewater Treatment, primary & sec. treatment might be enough. But for Industrial wastewater tertiary treatment is needed because of presence of sec. pollutants.

Typical coagulants used :- chemicals used for coagulation are :-

1.) Alum (Aluminium sulphate) if metal present then ppt. (flock)

$$Al_2(SO_4)_3 \cdot 18H_2O \xrightarrow{Ca(HCO_3)_2} CaSO_4\,(ppt)\downarrow + Al(OH)_3\downarrow + CO_2 + H_2O$$

2) Use $Fe_2(SO_4)_3$ (cheaper) → $Fe_2(SO_4)_3 + Ca(HCO_3)_2 \longrightarrow Fe(OH)_3\downarrow$ (flock) $+ CaSO_4\downarrow$ (ppt) $+ CO_2$

Wastewater → BOD/COD ration → x

(i) if $x > 0.5$ → go for biological treatment (like aerated lagoon)

(ii) if x very high (0.8 - 0.9) → a lot of CO_2 & CH_4 (C_6H_6) are produced. The process is not done in open atm. The CH_4 produced is collected and used in Burner etc. These are several techniques by which CO_2 can be seperated out completely & we get pure methane to be used as fuel & in various industrial processes.

(iii) if $x \simeq 1$ (ideally not possible) → no inorganic material (all biodegradable)

(iv) $x < 0.5$ → COD is high → significant portion of the organic ~~compour~~ matter in the wastewater is not readily degradable → COD methods used.

How to decide how much coagulating agent should be used?

depends on the nature of colloidal / suspended particles (size / density) surface area, wt of colloidal particles through density & volume.

1g $Fe(OH)_3$ → we know the surface area (amt. of reagent to be added on the mass of total colloids. chemical rxn eqn. balance → molar)

Mass of Total Colloids = No. of particles × Vol. × colloidal particle density

Use of $FeCl_3$ as flocculating agent :-

$FeCl_3 + Ca(HCO_3)_2 \rightarrow Fe(OH)_3 \downarrow + CaSO_4 \downarrow + CO_2 \uparrow + H_2O$ } particularly effective for phosphorous

In industrial treatment plant, branded materials like polyelectrolytes are used.

Some organic polyelectrolytes are also used for water treatment unit. Ex. - plant extract (jute) containing the electrolyte.

TSS → $Fe(OH)_3$ → clarification process to remove from chambers.

* BOD_5^{20} is roughly 68% of BOD u.

for wastewater containing vv high BOD → diluting is done bcoz then many days will be needed for decomposition.

$BOD_5^{20} = (DO_i - DO_f) \times$ Dilution factor (Ex. - 5 ml in 300 ml water → 300/5)

(oxygen depletion)

Performance of biological reactor :- (aerated lagoon, aerated reactor)

BOD removal follows first order rxn kinetics for BOD degradation

$k = k_D$ = d (oxygen rate for any wastewater stream.

BOD = L (Lt say) rate of BOD removal = $\frac{dL}{dt} = -k_D L$

$\int_{L_0}^{L} \frac{dL}{L} = -k\int_0^t dt \rightarrow L = L_0 e^{-kt}$

L_0 → BOD at t = 0

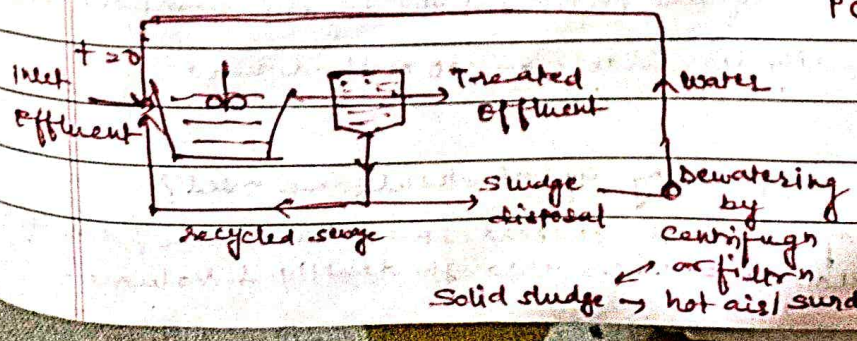
removal of BOD = $BOD_u - BOD_5^{20} = L_0 - L = L_0(1 - e^{-kt})$

$k_{20} = f(T)$ $\boxed{k_T = k_{T=20°C}\,\phi^{(T-20)}}$ $\phi_h = 1.03$ to 1.09 $k = 0.229/day \simeq 0.23/day$ (for aerated lagoon)

* Per capita BOD rate (kg of BOD per day needs to be fixed)

BOD discharge rate → (0.06 kg to 0.08 kg) / (Day × Person)

Population Equivalent = $\frac{\text{from Industrial wastewater BOD rate kg/day}}{\text{Per capita BOD rate}}$



How much time it will require to fill up? → $\frac{Vol.}{Q} = t$ (days)

if Q ↑ t ↓, BOD removal eff. ↓

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all wates should not be passed through ATP.
How much capacity needs to be accommodated during rainy season? Needs do popul^n equivalency to design ATP.

Sludge Loading rate = $\frac{\text{Mass of BOD}_5 / \text{day}}{\text{Mass of mixed liquor suspended particles}}$

Challenges w.r.t. to sludge disposal :- sludge → clay like material → remove water as large amt. of water will get wasted. otherwise → centrifug^n / filtr^n (Dewatering)
Solids → dried → sun drying / hot air

if DO content for a sample is found to be zero that data pt cannot be considered → will give an error in BOD calc^n → enough O_2 should be present in BOD bottle to get correct value

Phosphate detection process :- Stannous chloride method.

① rx^n with Ammonium molybdate - orthophosphate reacts in acidic condⁿ

② The rx^n forms molybdophosphoric acid which is further reduced to molybdenum blue by adding reducing agent → Stannous chloride/ascorbic acid.

③ The blue colour developed is measured at 690 or 880 nm within 10-12 mins. after colour development using a blank. The conᶜ is calculated using a std. graph.

④ The intensity of the blue coloured complex is measured which is directly proportional to the conᶜ of phosphate present in the sample.

N_2 (Ammonia) → Nesslerisation method.

Ammonia produces a yellow coloured compound when reacts with alkaline Nessler reagent ~~[illegible]~~. provided the sample is clarified properly. Pretreatment with $ZnSO_4$ & NaOH precipitates Ca, Fe, Mg and sulphide and removes turbidity & Apparent colour. Addⁿ of EDTA (before Nessler reagent) or Rochelle salt solⁿ prevents precipitⁿ of residual Ca and Mg in the presence of alkaline Nessler. Chemical rx^n of the method :-

$$2K_2HgI_4 + NH_3 + 3KOH \; (NH_2Hg_2IO) + 7KI + 2H_2O$$

Nil NO_3^- Nitrate) → UV spectrometer method.

In The method, NO_3^- is det by measuring the absorbance at 220 nm in sample containing 1 ml of Hydrochloric acid (1 N) in 100 ml sample. The conᶜ is calculated from graph from std. Nitrate solⁿ in range 1-1 1 mg/L as N.

Phenol Disulphonic Acid (PDA) method :

NO_3^- react with PDA and produces a nitroderivative which in alkaline solⁿ develops yellow colour due to rearrangement of its structure. The colour produced follows Beer's law and its intensity is proportional to the conᶜ of NO_3 present in the sample.

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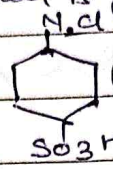
Nitrogen (NO_2^- Nitrite) – colorimetric method.

det. using ~~form~~ of reddish purple azodye at pH 2.0 – 2.5 by coupling diazotized sulphanilamide with N(1-Napthyl) ethylenediamine dihydrochloride (NED-dihydrochloride). The method is applicable to 1 µg NO_2^- N/L. The colour system obeys Beer's law up to 180 µg N/L with 1cm light path at 543 nm. The chemical rxn involved in the method is given :-

1.) $H_2SO_4 + HNO_2 + HCl \xrightarrow{\text{azodye}}$  (Diazonium Salt) + $2H_2O$

2.) Diazotisation rxn :- $R-NH_2 + NO_2^- + 2H^+ \longrightarrow R-\cdots N=N + 2H_2O$
(Sulphanilamide)

3.) Coupling rxn :-

$R-N=N + -R' \longrightarrow R-N=N-R' + H$ + [1-N-(1-Napthyle) ethylendiamine dihydrochloride]

$R \rightarrow SO_2.NH_2$ $R' \rightarrow -NH-CH_2-CH_2-NH_2$

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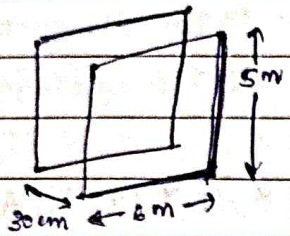
Q.1 A horizontal parallel plate ESP consists of 5m ht., 6m width with 30cm plate to plate spacing having a collect efficiency of 94.4% of a contaminated gas of 180 m³/min. The inlet loading of Particulate Matter (PM) is 10 g/m³. Cal. (i) bulk vel. of the gas.

(ii) outlet loading of the PM

(iii) particle migration vel.

(iv) find out the efficiency if volumetric flow rate of the gas is 1 by to 250 mg/min.

(v) find out the efficiency if the spacing is reduced by 10 cm



$\eta = 94.4\%$ $Q = \text{area} \times v = 180\ m^3/min$

inlet loading $= 10\ g/m^3$

(i) $v = \dfrac{180 \times 10^6}{30 \times 60 \times 5} = 2\ m/s$

(ii) outlet loading $= C_T$ inlet loading $= 10\ g/m^3$

$\eta = \dfrac{10 - C_t}{10} \times 100 = 94.4 \rightarrow C_t = \left(\dfrac{10 - 94.4 \times 10}{100}\right) = 0.56\ g/m^3$

(iii) $\eta = 1 - e^{v_{pm} A_c / Q}$ (A_c → convective surface area)

$e^{v_{pm}/3} = 1 - \eta \rightarrow v_{pm} = 3 \ln(1 - 0.944) = 0.144\ m/s$

(iv) $Q' = 250\ mg/min$

$\eta = 1 - e^{-(v_{pm} A_c / Q)} = 1 - \exp\left(-\dfrac{0.144 \times 6 \times 5 \times 2 \times 60}{250}\right)$

$\boxed{\eta = 87.4\%}$

(v) New spacing $= 30 - 10 = 20\ cm = 0.2\ m$

$\dfrac{v_{pm_1}}{v_{pm_2}} = \dfrac{S_2}{S_1} \rightarrow \dfrac{0.144}{v_{pm_2}} = \dfrac{20}{30} \rightarrow v_{pm_2} = 0.216\ m/s$

$\eta = 1 - \exp\left(-\dfrac{0.216 \times 6 \times 5 \times 2 \times 60}{180}\right) = 0.9867$

$\boxed{\eta = 98.67\%}$

Q.2 A stack gas flows through an ESP at the rate of 12 m³/s. The plate area is 250 m² and v_{pm} is found to be $2.8 \times 10^5\ d_p$

(i) Draw the grade efficiency curve for the particle ranging from 0.1 to 10μ

(ii) The plate spacing is 25cm. If the particle size distributions are as follows

Cal. the overall collecⁿ efficiency

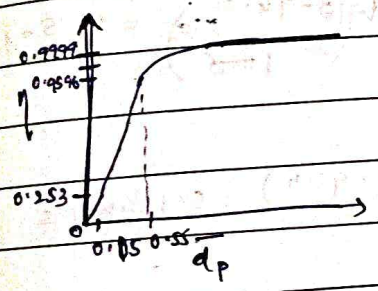
(c) If the plate spacing is reduced to 20 cm find out the efficiency.

Size range (μm)	wt % (gm)	$\bar{d_p}$	η
0 – 0.1	12	0.05	0.253
0.1 – 1	25	0.55	0.9596
1 – 2	30	1.5	0.9998
2 – 3	5	2.5	0.9999
3 – 4	13	3.5	0.9999
4 – 7	5	5.5	0.9999
7 – 10	4	8.5	0.9999
>10	6	10	0.9999.

(b) $\eta = 1 - e^{\frac{-v_{pm} A_c}{Q}}$ $Q = 12\ m^3/s$ $v_{pm} = 2.8 \times 10^5 \times \bar{d_p} \times 10^{-6}$ $A_c = 250\ m^2$

overall collecⁿ efficiency $= \sum \eta_i w_i = 90.016\%$

(a)



(c) $S_2 = 20$ cm $\frac{v_{pm_1}}{v_{pm_2}} = \frac{S_2}{S_1}$

$0.90016 = 1 - \exp\left(\frac{-v_{pm_1} \times 250}{12}\right) \rightarrow v_{pm_1} = 0.11\ m/s$

$v_{pm_2} = 0.14\ m/s$

$\eta = 1 - e^{\frac{-v_{pm_2} A_c}{Q}} = 0.945886$

Q3. A parallel plate type ESP having dimensions as 4m ht, 5m depth with spacing b/w plates as 25cm. Seperates dust from a flue gas at a T of 150°C and P = 1.05 kg/cm². The gas follows through the precipitator at the rate of 100 m³/hr where a voltage of 66000 V is applied. The particle size analysis shows the following distribⁿ :-

d_p (μm) = particle dia → $c = 1.0 + 0.172\ d_p$

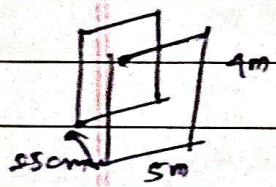
D_p (μm)	% wt	v_p
0.05	2	
0.1	15	
0.2	20	
0.4	33	
0.8	15	
1.2	10	
5.0	5	

cal:- (i) vpm (ii) overall collecⁿ efficiency.

(iii) overall collecⁿ efficiency if the T of the flue gas ↑ to 250°C due to malfunctioning of heat recovery sys.

(iv) if spacing is ↑ by 10 cm. What would be % change in overall collecⁿ efficiency keeping all other parameters constant

$l = 4m$ $w = 5m$ Spacing = 25 cm $T = 150°C$ $P = 1.05 kg/cm^2 = 1.05 \times 10^5$



$Q = 100 m^3/hr$ $E = \frac{66000}{25 \times 10^{-2}} = 264000 V/m$

$Q = \frac{100 m^3/s}{3600}$ $v_{pm} = \frac{q_{ut} E_c}{3\pi\mu d_p}$ $\mu = 0.015 \times 10^{-3}$ Pa.s (assu

$(q_{ut})_B = \frac{k_e}{} = 0.19 \times 10^{-19} r_p^2 E$

$$v_p = \frac{264000 \times (1.0 + (0.172) d_p) \times 0.19 \times 10^{-19} \times \left(\frac{d_p}{2}\right)^2}{3 \times 3.14 \times 0.015 \times 10^{-3} \times d_p}$$

$$= \frac{0.69696 \times 10^{11} \times d_p \times 10^3 \times 10^{-19} \times 0.19 (1 + 0.172}{4 \times 3 \times 3.14 \times 0.015 \times}$$

$$= \frac{0.1324224 \times 10^{-5} d_p (1 + 0.172 d_p)}{0.5652}$$

$$= 0.234293 \times 10^{-5} d_p (1 + 0.172 d_p)$$

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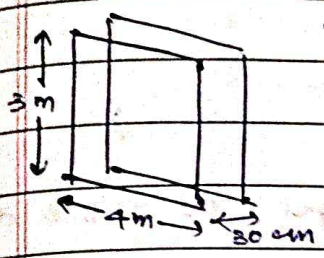
Q4. A horizontal parallel plate ESP having dimension as 3m ht., 4m depth with spacing b/w the plates as 30cm. Flow rate of gas is 10800 m³/hr. Inlet & outlet loadings are 27g/m³ and 1.6g/m³. Det.:- (i) Efficiency of collec^n (ii) v_{pm} (iii) Efficiency when flow rate is changed to 3 times the original flow rate. (iv) Change in efficiency when spacing is decreased by 4cm keeping all other parameters constant.



$Q = 10800\ m^3/h$

inlet and outlet loading → 27 g/m³ — 1.6 g/m³

(i) Efficiency of collection $= \eta = \frac{C_0 - C_t}{C_0} \times 100$

$= \frac{27 - 1.6}{27} \times 100 = 94.074\%$

(ii) $\eta = 1 - \exp\left(\frac{-v_{pm} A_c}{Q}\right) \rightarrow 0.94074 = 1 - \exp\left(\frac{-v_{pm} \times 4 \times 3 \times 2}{\frac{10800}{3600}}\right)$

$\rightarrow e^{-8v_{pm}} = 0.05926 \rightarrow -8v_{pm} = -2.825821$

$\rightarrow v_{pm} = \frac{2.825821}{8} = 0.353$

(iii) $Q' = 3Q \rightarrow \eta' = 1 - \exp\left(\frac{-0.353 \times 4 \times 3 \times 2 \times 3600}{3 \times 10800}\right)$

$\rightarrow \eta' = 1 - \exp(-0.389328)$

$\eta' = 61\%$

(iv) $\frac{v_{pm_1}}{v_{pm_2}} = \frac{S_2}{S_1} \rightarrow v_{pm_2} = \frac{30}{26} \times 0.353 = 0.4073\ m/s$

$\eta = 0.9615 = 96.15\%$ $\Delta\eta = \frac{96.15 - 94.074}{94.074} \times 100 = 2.2\%$ ↑

Q5. A gypsum plant emits 40000 m³/hr of off gases at 450°c and passes through a horizontal parallel plate type ESP having dimension as 4m high, 6m depth with spacing between the plates as 10 cm. Inlet & outlet loading are 3.325 g/m³ and 45 mg/m³. Cal.:- (i) Eff of collec^n (ii) v_{pm} (iii) Efficiency when flowrate is changed to 2.5 times the original flow rate (iv) change in efficiency when spacing is ↑ by 5cm keeping all other parameters constant.

(i) Efficiency $= \frac{C_0 - C_t}{C_0} \times 100 = \frac{3.325 - (45 \times 10^{-3})}{3.325} \times 100$

$= 98.6466\%$

$Q = \frac{\cancel{400}\,100}{\cancel{9}\,\cancel{36}} m^3/s = \frac{100}{9} m^3/s$

(ii) $\eta = 1 - \exp\left(-\frac{v_{pm} A_c}{Q}\right) = 1 - \exp\left(-\frac{v_{pm} \times 6 \times 4 \times 2 \times 9}{100}\right)$

$\rightarrow -4.32 v_{pm} = -4.30255 \Rightarrow v_{pm} = 0.996 m/s$

(iii) $\eta = 1 - \exp\left(-\frac{0.996 \times 6 \times 4 \times 2 \times 9}{2.5 \times 100}\right)$

$= 0.82112857$

$\eta = 82.113\%$

a

(iv) $\frac{v_{pm1}}{v_{pm2}} = \frac{S_2}{S_1} \Rightarrow v_{pm2} = \frac{S_1}{S_2} v_{pm1} \rightarrow v_{pm2} = 0.996 \times \frac{\cancel{20}\,4}{\cancel{25}\,5}$

$\rightarrow v_{pm2} = 0.7968 m/s$

$\eta' = 1 - \exp\left(-\frac{0.7968 \times 6 \times 4 \times 2 \times 9}{100}\right) = 0.968 = 96.8\%$

$\Delta\eta = \frac{98.6466 - 96.8}{98.6466} \times 100 = 1.87\% \downarrow$

Q6. A cement manufacturing plant emits 72000 m3/hr of flue gas at a T of 95°C and the flue gas is allowed to pass through a wire in tube type ESP where 60000 V is maintained between the discharging + collecting electrode which are 13.4cm apart. The ESP has a collecting surface area of 1000 m² to sep. alkaline dust particles from the cement plant. It may be assumed that most of the particles are charged by bombardment mechanism. sp gravity of the particle is 2.5 & $\mu = 0.015$ cal. :- (i) v_{pm} (ii) η of sep^n of 0.1 μm particle.

13.4 × 2 → dia, 13.4 only for discharging.

$Q = 72000 m^3/h$ $T = 95°C$ $E_c = \frac{60000 V}{13.4 \times 10^{-2} m} = 447761.194 V/m$

Collecting SA = $A_c = 1000 m^2$

$\rho = 2.5 g/cm^3 = 2500 kg/m^3$ $\mu = 0.015 \times 10^{-3}$ Pas

(i) $v_{pm} = \frac{q u_t E_c}{3\pi\mu d_p}$ $(q u_t)_b = ne$ $q u_{t,B} = q u_{t,b,E=2.5} * \frac{D_E = 2}{D_{E=2.5}}$

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

$(q u_t)_b = 0.19 \times 10^{-9} d_p^2 E = 0.19 \times 10^{-9} (13.4 \times 10^{-2})^2 \times E_c$

$(q u_t)_B = 0.19 \times 10^{-9} (13.4 \times 10^{-2})^2 E_c \times \frac{3/2}{5/3}$

Q7. A grit chamber is to be designed to remove particles of dia 0.2 mm with $\rho_p = 2.65\ g/cm^3$. The settling vel. has been found out in the range of 0.016 to 0.022 m/s for the particles depending upon their shape factor. Waste water is flowing at a rate of 10000 m^3/day at a vel. of 0.3 m/s which will be maintained at the inlet. Assuming depth of the chamber = 1m. find out the retention time as well as the dimensions of the chamber which is rectangular in shape.

Soln $Q = 10000\ m^3/day$ $h = 1m$ $V_w = 0.3\ m/s$ $D = 0.2mm = 0.2\times10^{-3}\ m$

$$Q = V\times A = \frac{10000}{24\times3600} \rightarrow A = \frac{10000}{24\times3600\times0.3} = 0.3858\ m^2$$

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1 m × width = 0.3858 m² → width = 0.3858 m ≃ 0.4 m

V_s = 0.016 to 0.022 m/s = 0.019 m/s (avg)

retention time = $\frac{\text{Depth}}{\text{Settling vel.}} = \frac{1}{0.019}$ = 52.632 s

$\frac{L}{V_w} = 52.632$ → L = 52.632 × 0.3 = 15.7896 m

$V_w = 0.3$

Dimensions :- h = 1 m = 3.28 ft.

L = 15.8 m = 51.8 ft

w = 0.4 m = 1.31 ft.

set. time = 52.632 s

Q5. Design a suitable chamber for an industrial wastewater plant at the rate of 4000 l/s. Assuming the flow vel. through the tank is 0.2 m/s and retention period of 2 min. The max. flow of the wastewater maybe assumed to be 3 times higher than that of a typical value reported in this problem. Assume that for removing the grit min. 0.45 m dead space to be provided. If in a certain day due to heavy rainfall, the storm water flowing through the chamber and the total stormwater accumulated is 5000 m³/hr. Suggest the suitable design modifications needed for the chamber.

1 m³ = 1000 L.

$Q = 4000\ l/s = \frac{4000}{1000}\ m^3/day = 0.4 \times 24 \times 3600\ m^3/day$

$= 0.4\ m^3/s.$

$\frac{1}{24 \times 3600}$

u = 0.2 m/s

retention period = 2 min = $\frac{\text{depth}}{\text{settling vel.}} = \frac{L}{\text{Flow vel.}}$

→ L = 2 × 60 × 0.2 = 24 m

cross sectional area req. = $\frac{Q}{V} = \frac{0.4}{0.2} = 2\ m^2$

Assuming water depth in the tank to be 1.2 m. we have

width = $\frac{\text{area}}{\text{depth}} = \frac{2}{1.2} = 1.67\ m \simeq 1.7\ m$

overall depth = 1.2 m + 0.3 m (free board space) + 0.45 (dead space)

= 1.95 m

Now $Q = 0.4\ m^3/s + \frac{5000\ m^3}{3600} = 0.4 + 1.389$

$= 1.789\ m^3/s$

Design a cyclone seperator to handle 80 m^3 / min of gases containing particles with density 2000 kg / m^3. The gas enters the cyclone at 80°C $\rho = 0.95$ kg/m^3 and $\mu = 0.025$ cP. The headloss across the cyclone is 8 times the vel. head which is 7.5 cm. The particle size distrib^n^s are :-

Dp (μm)	wt. %
0 – 5	5
5 – 10	10
10 – 30	45
30 – 50	25
> 50	15

As per the cond^n^s of pollution control board min. efficiency of 98% is req. Design the cyclone seperator and cal. the overall collec^n^ efficiency.

cyclone pr. drop (in millibar) $\Delta P = \frac{\rho_f}{2g_c}\left\{u_1^2\left[1+2\phi^2\left(\frac{r_t}{r_e}-1\right)\right]+2u_2^2\right\}$

ρ_f = gas density u_1 = inlet duct vel. u_2 = outlet duct vel.

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flow rate = 60 m³/min = $\frac{60}{60}$ m³/s = 1 m³/s

~~Assume inlet vel. = 25 m/s~~ Head loss = 8 × vel. head. = $8\times(\bar{v}^2/2g)$

→ $\rho_1 g h_1 = \rho_2 g h_2$ → $\rho_1 h_1 = \rho_2 h_2$ → $1000\times 7.5 = 0.95\times h_2$

→ $h_2 = \frac{7500}{0.95} = 7894.7368\,4$ cm → $h_2 = 78.9473684$ m.

→ $h_2 = \frac{8\times\bar{v}^2}{2g}$ → $78.9473684 = \frac{8\times\bar{v}^2}{2\times 9.8}$ → $\bar{v} = 13.9$ m/s

$Q = A\times\bar{v} = 1\ m^3/s$ (choosing high efficiency cyclone)

D_c = ? → $0.2D_c\times 0.5D_c\times\bar{v} = 1\ m^3/s$

→ $0.1D_c^2\times 13.9 = 1\ m^3/s$ → $D_c = 84.82$ cm = 0.8482 m

$D_{pc} = \left[\frac{9\mu_f b}{2\pi N V(\rho_p-\rho_g)}\right]^{1/2}$ $\Delta\rho_1 = \rho_p - \rho_f$ = std. cyclone, 2000 kg/m³

$\mu_1 = 0.018$ cP.

our D_c is too large compared with std. design diameter of 0.203 m.

Trying a combination of 4 cyclones in parallel, $D_c = 0.424$ m

Flow rate per cyclone = $\frac{1}{4}$ m³/s = 0.25 m³/s

at 80°C, $\mu = 0.025$ cP = 0.025×10^{-3} Pas $\rho = 0.95$ kg/m³

scaling factor = $SF = \frac{d_2}{d_1} = \left[\left(\frac{D_{c_2}}{D_{c_1}}\right)^3\times\left(\frac{Q_1}{Q_2}\right)\times\left(\frac{\Delta\rho_1}{\Delta\rho_2}\right)\times\left(\frac{\mu_2}{\mu_1}\right)\right]^{1/2}$

$SF = \left[\left(\frac{0.424}{0.203}\right)^3\left(\frac{223\ m^3/h}{50\times60\times60\ m^3/h}\right)\times\left(\frac{2000}{2000}\right)\times\left(\frac{0.025}{0.018}\right)\right]^{1/2}$

→ $d_2/d_1 = 0.114$. → $d_2 = 0.114\ d_1$

D_p (d_1)	① particle size	② wt%	③ mean particle size / scaling factor (d_2)	④ Efficiency at scaled size % (Using curve η vs (d_2/d_1))	collected grade ② − ④ / 100	grade at exit ② − ⑤
2.5	0−5	5	0.285			
7.5	5−10	10	0.885			% at exit
20	10−30	45	2.28			
40	30−50	25	4.56			
80	>50	15	5.7			

A_1 = Area of inlet duct = $(0.2d_2\times0.5d_2)\times$

A_s = Cyclone surface area = $\pi DL + \pi r^2$

f_c is taken as 0.005 $\psi = f_c A_s/A_1$

r_t/r_e = radius of the circle to which the ~~gas~~ center line of the inlet is tangential / radius of exit pipe

ϕ = factor, $f(\psi, r_t/r_e)$

Date: / /
Page:

Q10. An industrial WW was collected and diluted samples were prepared in std. 300 ml BOD bottle. The dil^n range, initial DO content & final DO content is given in the foll. table. Cal. avg. BOD.

cc. of raw wastewater	initial DO mg/L	final DO mg/L	BOD_5^{20}
3	8	5.2	280
6	8	3.83	202.5
9	8	2.38	187.33
12	7.9	1.38	163

$BOD_5^{20} = DO_i - DO_f \times$ Dil^n factor $= \frac{DO_i - DO_f \times 300}{\text{cc. of raw WW}}$

avg $= \frac{\text{Sum of all BOD's}}{4} = 209.71$ mg/L

Q11. 5 ltr. can → det BOD_5 of WW in steel industry → 500 ml BOD bottle incubated at 20°C for 5 days. Cal. avg. BOD_5^{20} → same as above procedure

Steel ind. WW vol., cc	initial DO mg/L	final DO mg/L	BOD_5^{20}
10	9.5	6.8	135
50	8.7	4.6	41
75	8.4	1.1	48.6666
100	8.3	0.0	

Insufficient supply of O_2 → don't consider this.

avg = 75 mg/L

Q12. The ultimate BOD (L_0) of an industrial WW sample is determined as 85% of COD. The COD of this WW is 500 mg/L. Considering 1st order BOD degradation exn the rate constant is 0.23/day. The T of the incubator is maintained at 27°C and the Temp. coeff. ϕ = 1.05 cal. Cal. the BOD value in mg/L for 3 days.

$k_T = k_{T=20°C}\, \phi^{(T-20)} = 0.23 \times (1.05)^{(27-20)} = 0.3236$ /day

$L_0 = 0.85 \times 500 = 425$ mg/L

BOD for 3 days $= L_0 e^{-kt} = 425 \times \exp(-0.3236 \times 3) = 160.98$ mg/L

Q13. An industrial WW is discharged at the rate of 3.5 Mn gallon/day. The BOD of WW is 1000 mg/L. The urban city where the industry is situated the BOD discharge rate is 0.080. Find out popul^n equivalent/day if :-

(i) Due to industrial dev. the WW discharge rate is ↑ to 5 Mn gallon/day. find out the % change in popul^n equivalent value

discharge rate = $3.6 \times 3.785 \times 10^6 = 13.2475 \times 10^6$ L/day

Population Equivalent ① = $\frac{\text{from industrial WW BOD rate kg/day}}{\text{per capita BOD rate}}$

$= \frac{13.2475 \times 10^6 \times 10^3 \times 10^{-6}}{0.080 \text{ kg/day. person}} = 165593.75$ kg/day

popul^n Equiv^nt ② $= ((5 \times 3.785 \times 10^6 \times 10^{-6} \times 10^3)/0.080) = 236562.5$ kg/day

% change $= ((① - ②)/①) \times 100 = 42.85\%$.

S14) The BOD of a treated wastewater which is discharged to the drain is 200 mg/L at 20°C. The BOD degradation rate const. at 20°C is 0.23/day. If the BOD test of treated effluent is conducted at 15°C for 9 days.

① cal. the BOD of treated effluent

② if the BOD degradation is carried out in an aerated lagoon of the same treated effluent at 30°C normal Temp. Cal. the performance of the aerated lagoon. The BOD of the treated effluent of the aerated lagoon is 50 mg/L

$BOD_5 = 200$ mg/L

68% of $BOD_u = BOD_5 \rightarrow BOD_u = \frac{200}{0.68} = 294.117$ mg/L

$\rightarrow \theta_L = (1.03 + 1.09)/2 = 1.06$

$\rightarrow k_T = 0.23 \times (1.06)^{(15-20)} = 0.172$/day

① $BOD = L_0 e^{-kt} = 294.117 \times \exp(-0.172 \times 9) = 62.55$ mg/L

② $BOD = 294.117 \times \exp\left(-0.23 \times (1.06)^{30-20} \times 9\right) = 294.117 \times 0.024551$

$= 7.221$ mg/L

(Cont. of ...)

6-11-2023

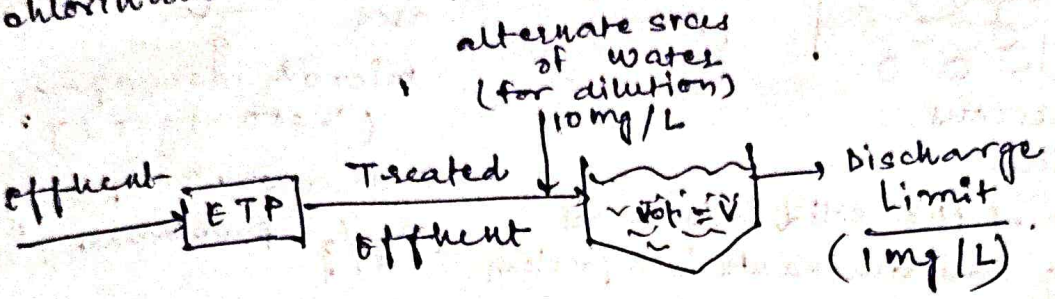
Tertiary Treatment Units :-

In Pesticide industry → basic pesticides which contribute to COD

Typical water pollutants from Alu processing industry → which constituent cannot be removed by primary & secondary treatment? ⇒ Fluorides

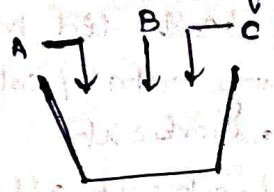
Acclimatated sludge process cannot reduce it

After BOD removal → sludge may contain various types of pathogens. For drinking water quality, we need to do chlorination even after wastewater treatment



after dilution contaminant amt may enter within discharge limit (acceptable quantity)

Total quantity of pollutants fed = $\frac{\text{Vol.} \times \text{Cont}}{\text{time}}$ (mg/L) = x gm of pollutant



A, B, C → pollution sources
Environment acts as a sink

Pollution Load :- Total amt. of pollutants coming and its retention time and overall impact on the locality.

→ Sample collection occurs at discharge pt., where it comes in discharge limits. However, with time, all the pollutants are stored in the environment as sink which leads to degradation of environment → which leads to ↑ in poll. load

Why Tertiary method need!

→ primary & sec. treatment not suff

→ dil^n may help bring acceptable discharge limit. But lots of water is consumed which may lead to ↑ pollution load.

Tertiary Treatment Processes :-

Chlorination → chlorinating agents → Disinfection process. Cl_2 dose

to kill pathogen

Cl_2

Cl_2 - Water

NaOCl.

(if residual chlorine is present it is harmful for us.)

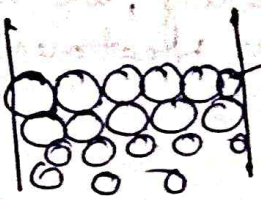
It is possible to kill all bacteria and viruses with extra doses of Cl_2. However it will lead to residual chlorine

for this we need to add Ca compound so that it reacts with Cl to form ppt and remove excess Cl_2 as its harmful for us

UV Radiation Treatment :- for killing pathogens
(eg. — aquaguards) → for disinfection of treated water

Adsorption → effluents like As, F^-, Cd^{2+}, Cr^{6+}, Pb^{2+}, other heavy metals can be removed by using adsorbents (solid materials porous in nature)

Ex.
activated carbon, graphene, activated Al., carbonaceous material.



→ solid materials (porous)

Adsorbent prop. :-

1.) surf. area = $\frac{m^2 \text{ of adsorbent}}{g}$
micro & macropores (>200 → good)

2.) max. adsorp^n capacity (mg/g of adsorbent)

→ Disposal of the solid adsorbents having contaminants is a problem.

Solid adsorbents loaded with pollutants → permissible limit

→ Ion exchange resins are used for adsorption
water + sp. pollutant ltd materials (porous)
(Heavy metals/color/F^-/As^-)

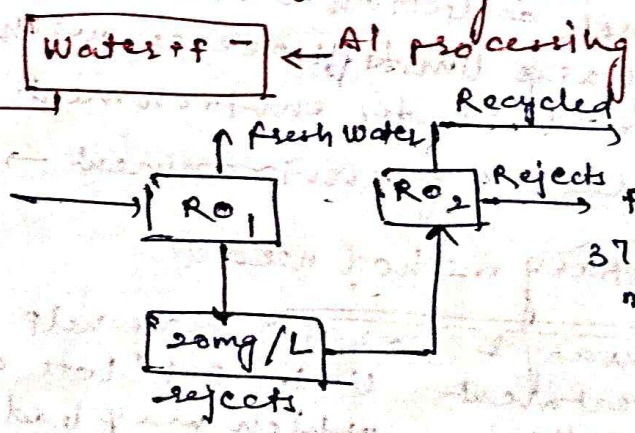
→ sterilisn of polluted adsorbent
→ incineration of the adsorbent after use
→ Toxicity Test → needs to be done for water & adsorbent (after use)

Membrane Seperation

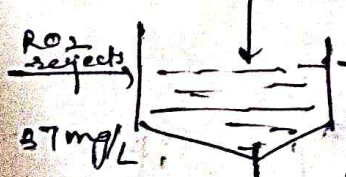
Reverse Osmosis

Ultrafiltrn

fluoride containing water from Al processing industries



Activated Alumina (Al_2O_3)



pH = 4.5 to 6.5 → Water
Cout = 1 mg/L

Discharge lt of F^- = 1.5 mg/L

→ Solid residue of Al_2O_3 → (electrochemical refining of Alumina occurs)

99.5% F^- removed

↑ pass hot flue gas to dry it up.

tal colloids. chemical rxn eqn balance — molar)

5* An acclimatated sludge plant is used to treat the pulp and papers industry wastewater at a rate of 3000 m^3/day. The 5 day BOD of the water is 200 mg/L. The AS process consists of 2 ~~aeration times~~ aeration ~~times~~ tanks each of 4m breadth & 5 m width & 25 m long. The mixed liquor suspended solids is 2100 mg/L. Calculate the (i) retention time (ii) Volumetric organic loading rate and (iii) sludge loading ratio.

Vol/Vol flow rat

mass of BOD load / day / Unit aeration Vol

Tertiary Treatment Process :-

7/11/23

Treated Effluent from 1° or 2° Treatment Unit (M1)
sometimes coagulation done after this

→ Ultrafiltration → Reverse Osmosis → Oxonation → UV Disinfection → O_3 Disinfec^n

(M3) (M2)

→ microfiltration → Reverse osmosis → Ion Exchange → Oxonation → O_3 disinfection

→ microfiltration → Reverse osmosis → UV Treatment → Cl_2 disinfection

⇒ Wastewater per million gallon per day Treatment → cannot be handled by tertiary treatment plant → (5 - 10 % will go through tertiary treatment units. → only if certain chemicals are present in the wastewater.)

→ replacement of membrane needed for RO, if all water is passed

→ Sec & Tertiary treatment units → high order of magnitude diffn. → ↑ cost

Distillation can also be used for tertiary treatment (heating of water to remove VOCs)

↑ energy needed

DM Plant → Demineralised plant → Along with primary treatment → ion exchange is used for getting quality water

Membrane process :-	operating pore size	pollutant that can be removed
Microfilt^n	> 50 nm	TSS, Turbidity, Cysts, bacteria Viruses, Protozoa
Ultrafilt^n	2 - 50 nm	Virus, Macromolecules, Colloids proteins, Bacteria
Nanofilt^n	< 2 nm	small molecules, Viruses
Reverse Osmosis	< 2 nm	color, sulphate, very small molecules, Nitrate, sodium & other salts
Electrodialysis	< 2 nm	Various Salt ions

(*) ⇒ Q = 3000 m^3/day, BOD_5^{20} = 200 mg/L, B = 4m, L = 25m, W = 5m

V = 2100 mg/L

(i) ① Vol. = 4 × 25 × 5 m^3 × 2 (aeration tanks) = 4 × 2 = 8 hours

Q = ~~6300~~

(ii) Volumetric organic loading rate = $\frac{\text{Total kg of BOD or other organic matter loaded/day}}{\text{Aeration vol. of WW}}$

$$= \frac{2000\ mg}{1000 \times 1000\ L} \times 1000\ \frac{L}{m^3} \times \frac{kg}{mg}$$

$$= \frac{2000 \times 10^{-3}\ kg/m^3 \times 300\ m^3/day}{100 \times 10\ m^3}$$

$$= 600 \times 10^{-3}$$

$$= 0.6\ kg/day \cdot m^3$$

(iii) Sludge loading rate = $\frac{\text{Mass of BOD entering aerator}}{\text{Mass of mixed liquor suspended solids}}$

$$= \frac{200\ mg/L \times 10^{-3}\ kg/m^3 \times 3000\ m^3/day}{2100\ mg/L \times 10^{-3} \times 25 \times 4 \times 8 \times 2}$$

$$= \frac{6}{21}$$

$$= 0.285$$

Q. An industrial WW sample was incubated ~~for 5 days~~ for 2 days at 20°C (BOD_2^{20}) and its BOD was found to be 200 mg/L. Cal. ultd. BOD of this WW. The rate constant value is 0.1/day

Soln $BOD_2^{20} = 200\ mg/L$ $\quad k_T = k_{T=20°C}\, \phi^{T-20}$

$L = L_0 e^{-kt}$ $\quad k_T = 0.1/day$

$200 = L_0 \exp(-0.1 \times 2)$ $\rightarrow \frac{200}{BOD_5^{20}} = \exp(0.2)$

$BOD_5^{20} = L_0 \exp(-0.1 \times 5)$

$\rightarrow 244.28\ mg/L = L_0$

$$\boxed{BOD_5^{20} = 148.163644\ mg/L}$$

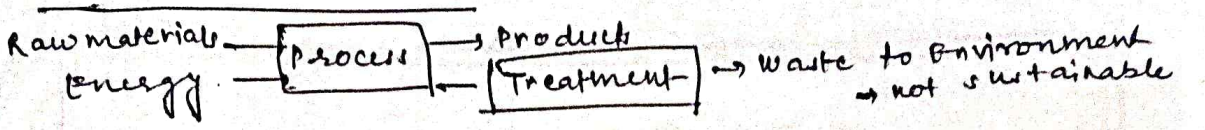
Management through waste minimizn :-

Industrial Waste Management practices

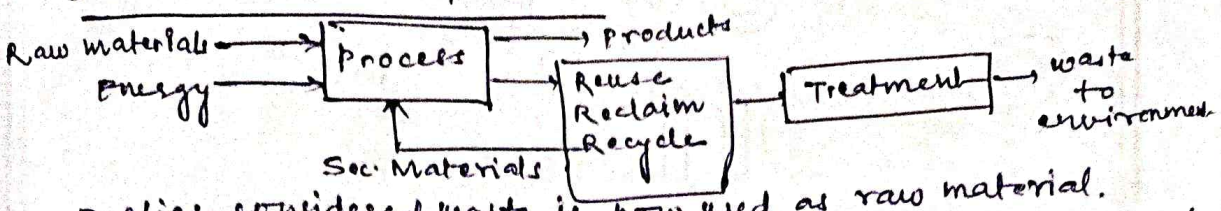
Materials → [Process] → Products
Energy → [Process] → waste to Environment → ↑ pollun → rivers pollutn

Early industrial practices

Later Industrial Practices :-



current Industrial practices :-



Earlier considered waste is now used as raw material.

Src redⁿ → an activity that reduces or eliminates the waste at the step where it is created. reduces that hazards to public health and the environment associated with such prod.

Emission redⁿ → related to the redⁿ or eliminⁿ of pollutants within industry boundary limits so they are not emitted into the environment

alternatives used. ↑ DDT ban, leaded petrol ban. ↑ sustainable retrd

Src redⁿ

- Prod. changes e.g.
  - Designs for Environment
  - Extend prod. life → make it robust to ↓ pollu load.
- Process changes
  - Material changes → change from plastic packaging to paper
  - Technology changes → DCOA for H_2SO_4 manufacturing
  - Operational changes.
    - ↓ full automation → quality control ↑ → [illegible]
- Material changes (changing or improving)
  - Material substitution
  - Material purification
- Technology changes
  - layout changes
  - Increased automation
  - Improved equipment
  - new technology
- Operational changes
  - operating & maintanence
  - mgt. practices
  - stream segregation
  - material handling improvements
  - prod. scheduling
  - Inventory control.

Installing Control Equipment

↓ Use of Control Equipment when all above attempts fail to control the pollution level. Mainly for particulate matters, gaseous pollutants