(1)

IPC-Numerical Set-3

Contents: (1) Electrostatic Precipitator

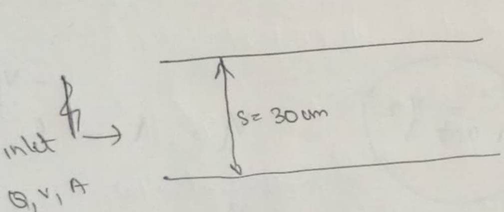
(2)

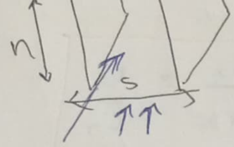
Q1. A horizontal parallel plate ESP consists of plate of 5m height and 6m length with 30 cm plate spacing and collection efficiency 94.4%. The flue gas enters the ESP at 108000 m^3/hr. Inlet dust loading is 10 g/m^3. Calculate (i) Inlet velocity of gas (ii) Outlet concentration of gas (iii) Dust particle migration velocity (iv) find the efficiency, if the flowrate is increased to 2 lakh m^3/hr. (v) find out the spacing efficiency if the spacing is 20 cm. vi) If instead of 2 parallel plates, 11 parallel plates are used, find Vpm for a flowrate of 200000 m^3/hr.

For parallel plate, ESP:

A_{cs} = spacing x height

i).





$v = ?$

$Q = AV$

$A_{cs} = s \times h = \frac{30}{100} \times 5 = 1.5 m^2$

$Q = 108000 \ m^3/hr$

$\boxed{Q = VA}$

$Q = \frac{108000}{3600} = 30 m^3/s$

$v = \frac{Q}{A} = \frac{30}{1.5} = 20 m/s$

ii) 94.4%

$\frac{94.4}{100} = \frac{C_{inlet} - C_{outlet}}{C_{inlet}} \Rightarrow 0.944 = \frac{10 g/m^3 - C_{outlet}}{10 g/m^3}$

$\Rightarrow 9.44 = 10 g/m^3 - C_{outlet}$

$\Rightarrow C_{outlet} = 0.56 \ g/m^3$

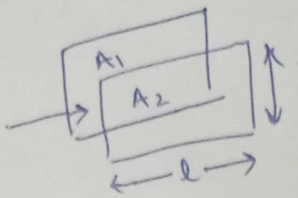
C_{outlet} (in mg/m^3) = 560 mg/m^3

iii) $\boxed{\eta = 1 - e^{\frac{-V_{pm} A_c}{Q}}}$

$A_c \rightarrow$ collection area.

for 2 plates,

$A_c = A_1 + A_2$



$= lh + lh$

$A_c = 2lh$

~~collection area~~

$l = 6, \; h = 5$

$A_c = 2 \times l h$

$= 2 \times 6 \times 5 = 60 \, m^2$

$V_{pm} = ?$

$Q = 30 \, m^3/s$

$0.9449 = 1 - e^{\frac{-V_{pm} \times 60 m^2}{30 m^3/s}}$

$e^{\frac{-V_{pm} \times 60^2}{30}} = 0.56056$

$V_{pm} = 1.44 m/s$

iv) If $Q = 200000 \, m^3/hr$

$\boxed{\eta = 1 - e^{-V_{pm} A_c / Q}}$

$\frac{200000}{3600} = \frac{500}{9} = 55.56 \; m^3/s$

$\eta = 1 - e^{\frac{-1.44 \times 60}{55.56}} = 78.8\%$

v) If spacing is 20.

$\boxed{\frac{V_{pm1}}{V_{pm2}} = \frac{V_1}{S_1} \times \frac{S_2}{V_2} = \frac{E_1}{E_2}}$

V_1 and V_2 $=$

$\eta = 1 - e^{\frac{-V_{pm} \times 60}{30}}$

$\eta_{VPM} = 98.67\%$

$\boxed{\frac{V_{pm1}}{V_{pm2}} = \frac{S_2}{S_1} =}$

$\frac{1.44}{V_{pm2}} = \frac{20}{30}$

$V_{pm} = \frac{1.44 \times 3}{2} = 0.72 \times 3$

$= 2.16 m/s$

vi) 11 parallel plates

1 parallel plate $\Rightarrow$ $A_c = h \times L = 30 m^2$

11 parallel plates $\Rightarrow$ $A_c = 11 \times h \times L = 330 m^2$

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

$0.056 = e^{\frac{-V_{pm} \times 330}{55.56}}$

$\frac{V_{pm} \times 330}{55.56} = 2.882$

$\Rightarrow V_{pm} = 0.485 m/s$

(3)

As a recently hired for an equipment manufacturing company, Tony has been assigned a job to treat 132000 m^3/hr gas containing gypsum particle from a gypsum particle. The gypsum inlet is 77.6 g/m^3 and outlet loading is 1140 mg/m^3. Submit the Design report of the ESP.

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

$$= \frac{77600 - 1140}{77600} \times 100 = \underline{\underline{98.53\%}}$$

$$\boxed{\eta = 1 - e^{-V_{pm} \cdot A_c / Q}}$$

V_{pm}, A_c are unknown

$Q = 132000\ m^3/hr$

$= \frac{132000}{3600} = \underline{\underline{36.67\ m^3/s}}$

• Typically, $V_{pm} \rightarrow 0.14\ m/s$ to $0.18\ m/s$

So, we take $V_{pm} = \frac{0.32}{2} = \underline{\underline{0.16\ m/s}}$

$$\eta = 1 - \exp\left(-\frac{0.16 \times A_c}{36.67}\right)$$

$$1 - 0.9853 = \exp(-0.16 \times A_c / 36.67)$$

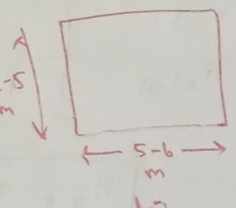
$$A_c = \underline{\underline{967.15\ m^2}}$$

⇓

collecting Area.

~~Typi~~ Maximum ~~height~~ length of ~~cyclone~~ ESP is ~~6~~ 6 m.

maximum ht of ESP is 5 m.



Area of one plate = 5×6 $= \underline{\underline{30\ m^2}}$

Total no. of plates required $= \frac{967.15}{30}$

$= 32.23$ plate

$\approx \underline{\underline{33\ \text{plates}}}$

The minimum spacing required is 30 cm.

∴ s = 30 cm.

(4)

Q3. A stack gas flows through an ESP ~~at~~ at the rate of $12\ m^3/s$. plate area is $250\ m^2$ and Vpm has been found to be :

$$V_{pm} = 2.8 \times 10^5\ D_p\ m/s$$

(i) ~~Draw a particle size efficiency~~ curve for particles ranging from 0.1 to 10 μm, The plate spacing is 25cm.

(ii) If the size distribution of the particle is given below, calculate the overall efficiency.

(iii) If the plate spacing is reduced to 20cm, Calculate the efficiency.

Size range (μm)	0-0.1	0.1-1	1-2	2-3	3-4	4-7	7-10
wt (gm)	12	25	30	11	13	5	4

1)

Size Dp Range	wt (gm)	wt (%)	$V_{pm} = 2.8 \times 10^5\ D_p$ (m/s)	η_i	$\eta_i w_i$
0.05	12	12%	0.014	~~0.25~~ 0.25	
0.55	~~12~~ 25	25%	0.154	0.95.95	
1.5	~~25~~ 30	30%	0.42	0.99.98	
2.5	~~30~~ 11	11%	0.7	0.99.99	
3.5	~~12~~ 13	13%	0.98	0.9999	
5.5	~~10~~ 5	5%	1.54	0.9999	
8.5	4	4%	2.38	0.9999	
Total	100				

$$\boxed{\eta_T = \eta_i w_i}$$

$$\eta_i = 1 - e^{\left(-V_{pm} A_c / Q\right)}$$

$$\eta_i = 1 - e^{\left(-V_{pm} \times 20.83\right)}$$

* Dont ~~forget~~ convert μm → m for ~~kan~~ substituting in Vp.

it becomes $(\times 10^{-1}) \times 2.8$

$$\eta_T = 89.92\%$$

$$\boxed{\frac{V_{PM_1}}{V_{PM_2}} = \frac{S_2}{S_1}}$$

Initially, Tray spacing, $S_1 = 25\,cm$

New Tray Spacing, $S_2 = 20\,cm$.

$V_{PM_2} = \frac{V_{PM_1} \times S_1}{S_2} \Rightarrow V_{PM_2} = \frac{25}{20} \times V_{PM_1} \Rightarrow \boxed{V_{PM_2} = \frac{5}{4} V_{PM_1}} \Rightarrow \boxed{V_{PM_2} = 1.25\,V_{PM_1}}$

V_{PM_1}	0.014	0.154	0.42	0.7	0.98	1.54	2.38
V_{PM_2}	0.0175	0.1925	0.525	0.875	1.225	1.925	2.975

$\bar{D}_p$	wt %	η_i
0.05	12%	0.3055
0.55	25%	0.9818
1.5	30%	0.9999
2.5	11%	0.9999
3.5	13%	0.9999
5.5	5%	0.9999
8.5	4%	0.9999

$\eta_i = 1 - e^{(-V_{PM_i} \times 20.833)}$

$\eta_T = \eta_i w_i = 91.2047\,\%$

[check Answer]

Qu. A wiring type ESP having collecting electrode total surface area of $300\,m^2$ to separate Alkaline dust particle from a cement manufacturing plant. The flue gas flows through the ESP at 72000 m^3/hr through the ESP wire, a voltage of 56000 V is maintained b/w discharged and collecting electrode which are 12.5 cm apart.

(i) Calculate the particle migration velocity.

(ii) Efficiency of separation for PM particle.

$\rho_{particle} = 2500\,kg/m^3$ $\mu_{gas} = 0.0225\,cP$

Assume diffusional mechanism charges the particle predominantly in the ESP.

The correction factor $C = 1 + \frac{0.172}{D_p}$

(6)

$$\boxed{V_{PM} = \frac{q_{et} \times E \cdot C}{3\pi \mu d_p}}$$

$q_{et} \Rightarrow$ limiting electric discharge
$C \Rightarrow$ cunningham correction factor.
$E \rightarrow$ Electric field (V/m).
$\mu \rightarrow$ Gas viscosity
$d_p \rightarrow$ particle dia in micron.

$q_{lt} = n \times e$ $\quad e = 1.6 \times 10^{-19}$

let $n = 10$

$q_{et} = 10 \times 1.6 \times 10^{-19} = \underline{1.6 \times 10^{-18}}$.

$C = 1 + \frac{0.172}{0.1} = 1 + 1.72 = \underline{2.72}$.

$\mu = 0.0225\,cP = \underline{0.0225 \times 10^{-3}}\ Pa \cdot s$

$E = V/d = \frac{56000}{12.5 \times 10^{-2}}$

$= \underline{448000}\ V/m$.

$d_p = 0.1 \times 10^{-6}$

$$V_{pm} = \frac{1.6 \times 10^{-18} \times 448000 \times 2.72}{3 \times 3.14 \times 0.0225 \times 10^{-3} \times 0.1 \times 10^{-6}}$$

$= \cancel{0.09198}\ 0.09199\ m/s$

$Q = 72000\,m^3/h$

$\frac{72000}{3600} = \underline{20\ m^3/s}$

$A_c = 300\,m^2$

$\eta = 1 - e^{-V_{pm} A_c / Q}$

$= 1 - e^{-0.09199 \times 300 / 20\,m^3}$

$= \underline{0.7483}$

An ESP must be designed to process $300\, m^3/min$ of a stack gas. The particle migration velocity which passes through the ESP can be calculated from the formula:

$$V_{PM} = 1.5 \times 10^5 D_p \ m/s$$

(i) Calculate the plate area required to remove particles of diameter 0.7 μm so that 95% removal efficiency is achieved by the ESP.

(ii) Draw the ~~pat~~ particle migration velocity profile along with their individual efficiency, given that particle size range is in b/w 0.01 to 0.05 μm in the stack gas.

(iii) If 95% of the particle is greater than 0.1 μm. What will be the overall collection efficiency?

(iv) If flow rate of gas is suddenly changed to $7.5\, m^3/s$. What will be the change in efficiency?

$Q = 300\, m^3/min = \underline{5 m^3/s}$ $\quad$ D_p is in meter.

$$V_{pm} = 1.5 \times 10^5 \ D_p \ m/s.$$

i) $\eta = 0.95$ $\quad$ $D_p = 0.7\, \mu m = \underline{0.7 \times 10^{-6}}$.

$$V_{pm} = 1.5 \times 10^5 \times 10^{-6} \times 0.7$$

$$= \underline{0.105\, m/s}$$

$$\boxed{\eta = 1 - e^{-V_{pm} A_c / Q}}$$

$$1 - 0.95 = \exp\left(-\frac{0.105 \times A_c}{5}\right) \Rightarrow \ln(0.05) = -\frac{0.105 \times A_c}{5}$$

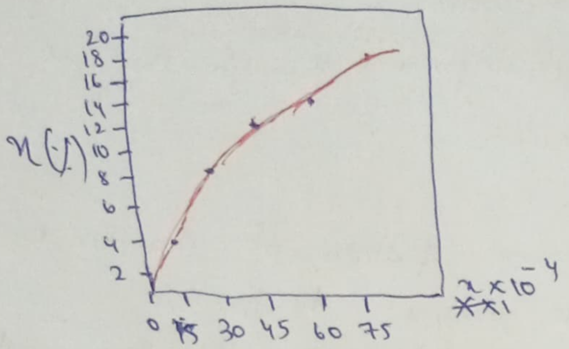
$$A_c = \underline{142.653\, m^2}.$$

ii)

$\bar{D}_p$	0.01	0.02	0.03	0.04	0.05
$\bar{V}_{pm}$	0.0015	0.003	0.0045	0.0060	0.0075
η	0.0418	0.08203	0.120487	0.1573	0.19263

$$\eta = 1 - e^{-\frac{V_{pm} \times 142.653}{5}}$$

$$\underline{\eta = 1 - e^{-28.5306 V_{pm}}}.$$



[please draw as ~~dra~~ a curve]

(iii) ~~A~~ ~~95~~ wt. particle size distribution

		wt %	$\bar{D}_p$	~~x_i~~	$x_i v_{pm}$
①	0 – 0.1	5%	0.05		~~0.1926~~ 0.0075
②	> 0.1	95%	$\frac{\cancel{20}+0.1}{2} = \cancel{5}.05$ (10)		~~0.7575~~ 1.5075 [~~Take~~ Doubt ?]

or take till 100 μm

$v_{pm_1} = 1.5 \times 10^5 \times 0.05 \times 10^{-6} = 0.0075$

$\eta_i = 1 - e^{v_{pmi} \times 28.5306}$

η_i

0.1926

~~0.7575~~

~~0.9999~~ 100

$\eta_T = 95.96\cancel{29}$ 3

Generally, ESP operate @ 1–10 μm range. Above 10 μm, we ~~d~~ relay more on ~~pre-treatment~~ step other devices as cyclone. Take 0–20 μm. (consider 0 – 20 μm)

⇓

According to sir.

iv) $Q = 7.5\ m^3/s$ $\quad V_{pm} = 0.105\ m/s$ [calculated before]

$A_c = 142.\cancel{5306}\,653\ m^2$

$\eta = 1 - \exp\left(-\frac{0.105 \times 142.5306}{7.5}\right)$

$= 0.8642\cancel{6}$ $\quad \eta = 86.42\%$

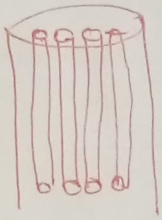
(9)

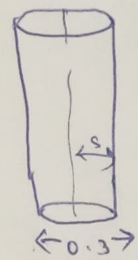
A cylindrical ESP of diameter 0.3m is used for separating a furnace gas stream. If the volumetric flow rate of the gas is 250000 m³/hr. i) what will be the length of the precipitator for obtaining a collection η of 99.9%. ii) what % change in electrode collection area is required to ↑ the collection efficiency to 99.95 ?

$$Q = 250000\ m^3/hr = \frac{250000}{3600} = \underline{69.44\ m^3/s}.$$

multiple tubes will be required.

$$\eta = 1 - e^{-V_{pm}A_c/Q} \qquad A_c = \cancel{2x}\ 2\pi r h$$





multiple tubes will be required.

$\cancel{0.3}$ $\cancel{B}$ $\cancel{69.44\ m^3/s}$

$$\eta = 1 - e^{-(V_{pm}A_c/Q)}$$

$$\eta = 99.9\% = \underline{0.999}.$$

$$S = \underline{0.15m}.$$

$$V_{pm} = \frac{\cancel{8}\, q_{st}\cdot E\cdot C}{3\pi \mu d_p}.$$

$$A_c = \pi r^2 h$$

The usual migration velocity of precipitator.

(10) (11)

Q

A parallel plate ESP having dimensions 4m high, 6m depth with spacing b/w the plates as 30 cm separate dust from a flue gas at a temperature of 130° C and 1.03 kg/cm². The gas flows through precipitator at a rate of 70000 m³/hr. when a voltage of 70000 V is applied. The Particle size analysis shows the following distribution.

Dp (μ)	0.05	0.1	0.2	0.4	0.8	1.2	5
% weight	1	16	25	28	10	16	2

$C = 1.0 + 0.170/dp$ where dp is particle diameter in micron

Calculate

i) Particle migration velocity.

ii) Overall collection efficiency.

iii) Overall collection efficiency, if temperature of flue gas is increased to 150° C due to malfunctioning of heat recovery system

iv) If the spacing is increased by 10cm what would be the % change in overall collection efficiency keeping all other parameters constant?

v) Prepare a grade efficiency profile for the entire range of particles.

$$\boxed{V_{pm} = \frac{q_{lt} \times E \cdot C}{3\pi \mu D_p}}$$

C → cunningham correction factor.

μ → gas viscosity.

Dp → particle diameter in micron.

E → Electric field (v/m)

qlt → limiting Electric discharge.

spacing = 30cm = 0.3m

$$E = \frac{70000\,V}{0.3\,m} = 233333\,V/m$$

$q_{lt} = n \times e$ n is the no. of electronic charge

$e = 1.6 \times 10^{-19}$ C

(12)

PV = nRT

$\Rightarrow$ $\boxed{1\,kgf/cm^2 = 98{,}066.5\ Pa}$

$1.03 = 98{,}066.5 \times 1.03 = 101008.495\ Pa$

$T = 130^\circ C = 130 + 273 = 403\,K$

for $\boxed{q_{eff}/b = 0.49 \times 10^{-9} \times \delta p^2 E}$

$\boxed{PV = nRT}$ $V = 4 \times 6 \times \frac{30}{100} = 7.2\,m^3$ $Q = 70000\,m^3/hr$

$= 19.44\,m^3/s$

for $101008.495 \times 19.44 = n \times 8.314 \times 403$

$n = \cancel{586.1899}$ $e = 1.6 \times 10^{-19}$

V_{pm} $q_{et} = 586.1899 \times 1.6 \times 10^{-19} = 937.903 \times 10^{-19}$

$V_{pm} = \frac{q_{et} \times E \times C}{3\pi \mu d_p}$ $\mu = 0.018\,cP$

$= 0.018 \times 10^{-3}\ Pa\text{-}s$

$V_{pm1} = \frac{937.903 \times 10^{-19} \times 233333.33 \times 3.4}{3 \times 3.14 \times 0.018 \times 10^{-3} \times 0.05}$ $C = 1 + \frac{0.170}{0.05}$

$= \frac{937.903 \times 10^{-16} \times 233333.33 \times 3.4}{3 \times 3.14 \times 0.018 \times 0.05}$ $= 3.4$

$= 877647679\cancel{52.8} \times 10^{-10}$

$8.77647\,m/s$

$n = \frac{PV}{RT} = \frac{101008.495 \times 7.2\,m^3}{8.314 \times 403} = 217.0577$

$q_{et} = n \times e = 347.292 \times 10^{-19}$

$\boxed{V_{pm} = \frac{q_{et} \times C \times E}{3\pi \mu D_p}}$ $V_{pm} = \frac{347.292 \times 10^{-19} \times 233333.33\ C}{3 \times 3.14 \times 0.018 \times 10^{-3} \times D_p(m) \times 10^{-6}}$

$V_{pm} = \frac{47791223 6.6 \times 10^{-10} \times C}{D_p(\text{in } m)}$

(13)

$\underline{0.05}$.

$C = \frac{\cancel{2}1 + 0.170}{0.05} = \underline{4.4}$.

$V_{pm} = \frac{4\cancel{7}791223\cancel{6}2 \cdot 6 \times 10^{-10} \times 4.4}{0.05} = \underline{4.205\ m/s}$

ii) $D_p = 0.1$

$C = \underline{2.7}$.

$V_{pm} = \underline{2.29\ m/s}$ [check for calc mistake]

iii) $D_p = 0.2$.

$C = 1.85$

$V_{pm} = 0.44\ m/s$

iv) $D_p = 0.4$

$C = \underline{1.425}$.

$V_{pm} = 0.170\ m/s$

iv) $D_p = 0.8\ m/s$

$C = 1.2125$

$V_{pm} = \underline{0.07256}\ m/s$

v) $D_p = 1.2$.

$C = \underline{1.14}$.

$V_{pm} = 0.\cancel{072}045\underline{4}\ m/s$.

vi) $D_p = 5$

$C = 1.034$

$V_{pm} = \underline{0.0099}\ m/s$.

n) Overall collection η calculation

$\bar{D}_p$	wt fractn	V_{pm}	η	$\eta_i w_i$
0.05	1	4.2 m/s	0.9999	
0.1	16	2.29 m/s	0.9964	
0.2	25	0.44 m/s	0.66	
0.4	28	0.170 m/s		
0.8	10	0.07256 m/s		
1.2	16	0.0454		
5	2	0.0099 m/s		

$\eta = 1 - e^{-V_{pm}A_c/Q}$.

$\boxed{\eta = 1 - e^{-2.4691 V_{pm}}}$

$A_c \to$ collecting Area.

$A_c = 4 \times 6 \times 2 = \underline{48\ m^2}$.

$Q = \frac{70000\ m^3/hr}{3600}\ m^3/s = \underline{19.44\ m^3/s}$

(check the Answer).

C_{outlet} (in mg/m^3) = $\underline{560\ mg/m^3}$