ESP

- Device for removing

  Fine suspended particles from Gas by charging particles in Corona and separating them from gas by electric field

- Annual Coal fly ash : 2×10^7 tons In Electric Power Generation

➢ E Power	:	60%
➢ Cement	:	10%
➢ Paper	:	7%
➢ Chemical	:	6%
➢ Steel	:	10%
➢ Nonferromat	:	7%

-Sizes - Dep. on application / high Capital cost

Modular in nature - 10,000 – 25,000 ft^3/min

Segment s - Expandable

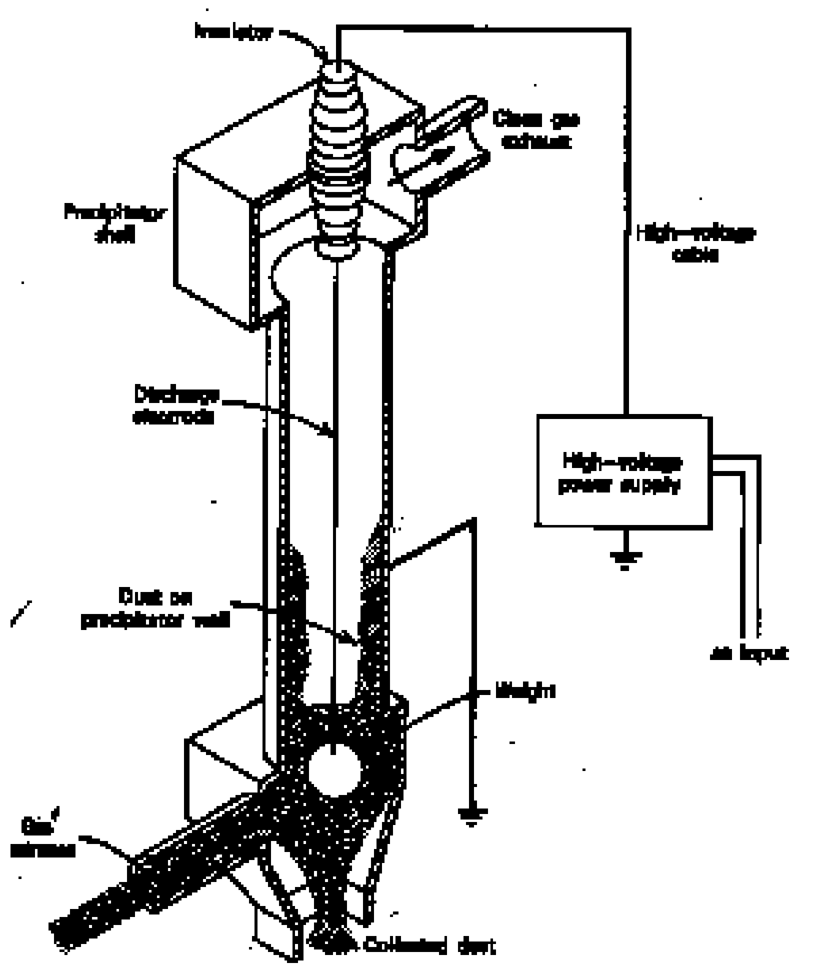
-Smaller units for air cleaner(indoors)

Types-

Tubular – pipe

Duct – plate

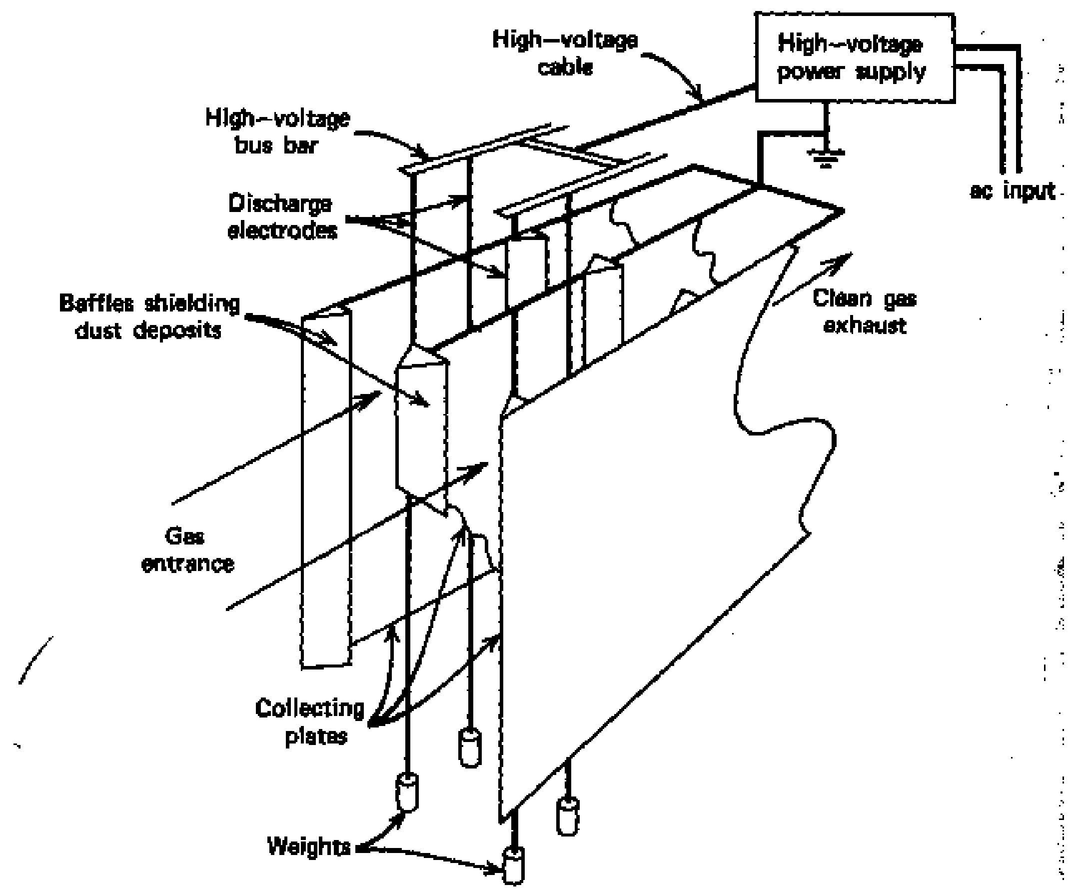
Tubular – pipe



(a)

1. Single-stage electrostatic precipitators: (a) Tubular. (Used with permission of Wesley Publishing Company.)

Duct – plate



(b)

Figure 9.1. (b) Duct type. In both cases the corona discharge and precipitating field ex over the full length of the apparatus.

Tubular:

- Grounded Cylindrical-collection Electrode
- Coaxially – a high Potential wire corona discharge electrode

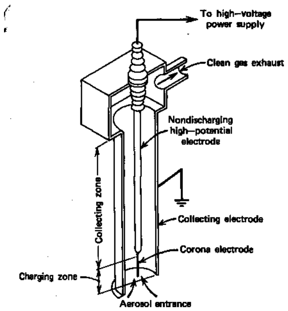
Duct:

- Two parallel Grounded Plates
- Array of parallel discharge wires – in a plane midway

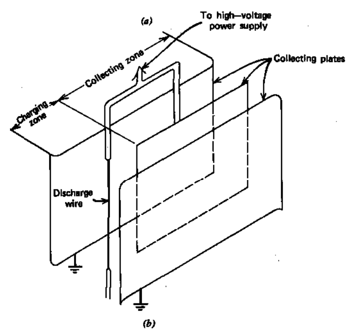
Gas:

- with solid/liquid impurities passed through tube/duct.
- At sufficient voltage(Potential difference)-wires start Coronating

2 Stage Pipe


To high–voltage power supply
Clean gas exhaust
Nondischarging high–potential electrode
Collecting zone
Collecting electrode
Corona electrode
Charging zone
Aerosol entrance

2 Stage Duct


(a)
To high–voltage power supply
Collecting zone
Collecting plates
Charging zone
Discharge wire
(b)

Corona:

- Copious supply of ions(similar to wire polarity)
- While moving along E field ions attach to particles
- Charged particles attracted(or rather) collected on the collecting electrode- adhere removed by rapping/flushing – fall in a hopper
    - ✓Liquid forms a film on the collector dripping later
- 2 stage – Domestic Air cleaning

History:

Gilbert - 1600 - frictionally charged dielectric attract dust.
Von Guericke 1670 – Man made Corona Application.

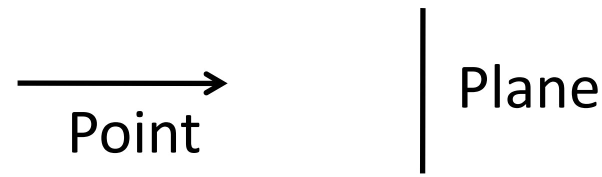
Boyle,Newton,Franklin,Coulomb-faraday- fine particle E.S

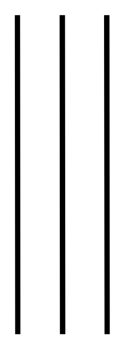
F.G.Cottrell - 1907-Modern ESP, Tr.& rectifier Fine wire electrodes, negative corona improvement in rectifiers

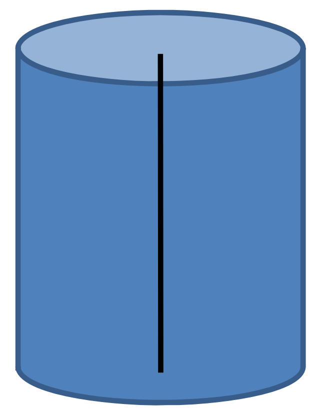
Corona Formation:

1-2 electrodes

Radius of curv. of 1 << Radius of Curv. 2







Coaxial wire and pipe

- ✓As the voltage is raised region surrounding(sharp) or electrode of low radius of curvature will break at a voltage less than gap (sphere) breakdown voltage 30 kVp @STP
- ✓This form of incomplete or partial discharge $\underline{\Delta}$ Corona
- ✓Appears as highly active region of glow
- ✓Positive electrode – uniform and smooth
- ✓Negative electrode - concentrated in tufts at intervals
- ✓Free e^- availability in the region High E field in gas

Negative :

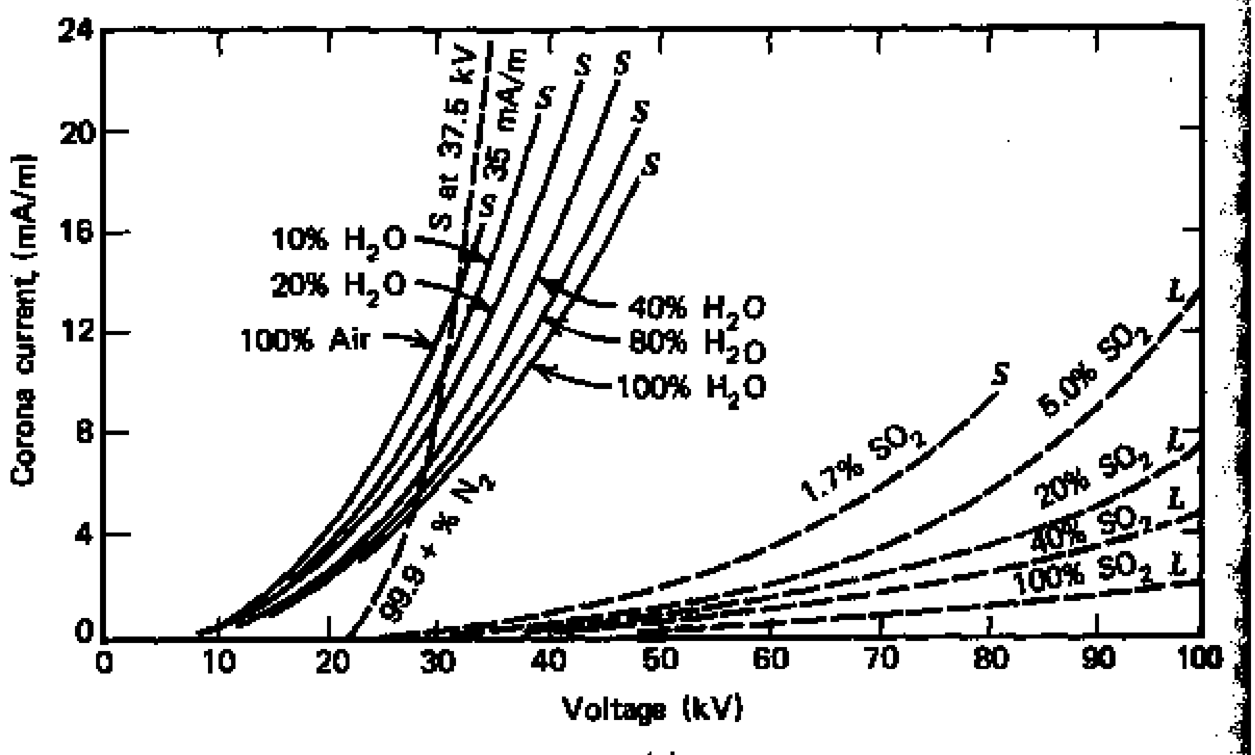
- ✓Free e^- gain energy and produce +ve ions & e^- collision – Secondary e^- accelerated – ionized further => e^- avalanche; +ve ions are accelerated towards wire – release further e^- (maintain discharge.) far away from wire they attach O_2 and from –ve ion unipolar dense cloud fills most of the space; determine the current outside corona region this- limits/ stabilizes discharge

Positiveve :

- ✓Positive ions carry the current.

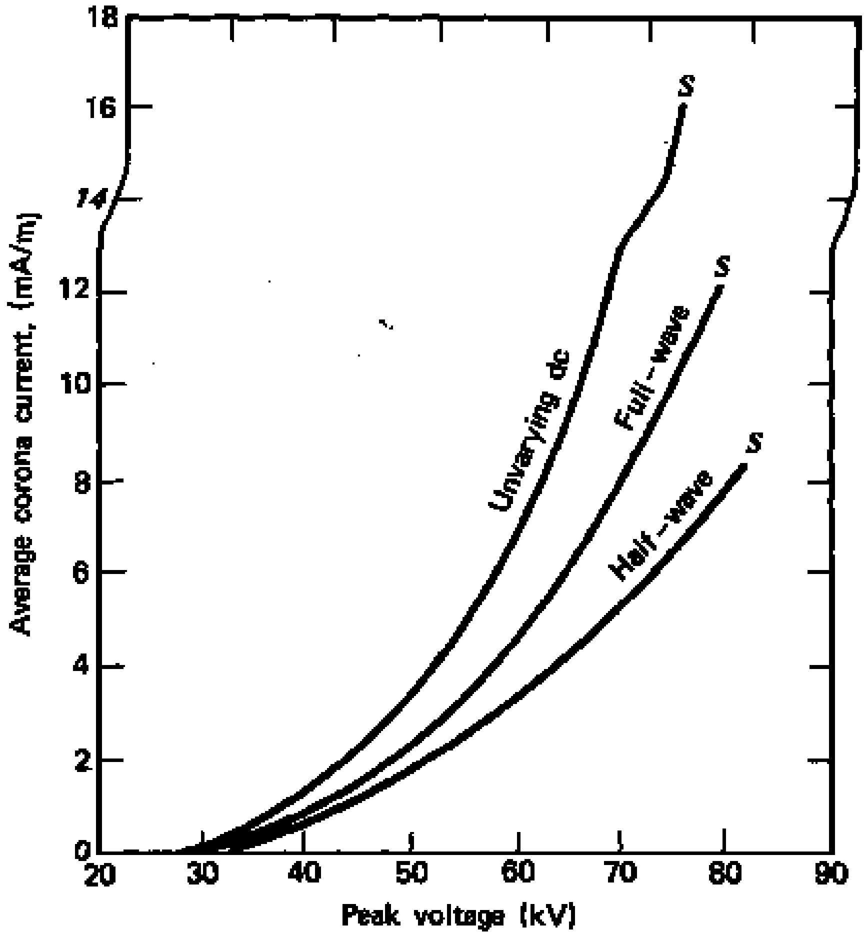
fig 9.3

Effect of Gas: L-limit of Power Supply, S-SOV
7.6 Cm with 0.25 mm wire for air
15.2 cm with 2.8mm wire for S02



(a)

I-V relations for 15.2 cm with 2.8mm



(b)

-ve discharge :

✓Higher current – Sov.

✓Reth upper limit to ESP operation

-Domestic Air Cleaning :

✓Positive Corona ozone is physiologically objectionable ozone in Greater quantities

✓Air at room Condition. Valid – broad PT ranges for variety of gasses

E - attachment :

✓Electronegative nature of Gas.

✓Depends on presence of gases/vapour.

✓Insert gases/H_2 – donot attach

✓Employ positive Corona – in such cases.

✓Commercial Grade- gases- contain Electronegative impurities.

Current Voltage Field Relation:

Wire- pipe Geometry:

Coaxial wire- Cylinder.

$E = -\partial V/ \partial r$ ----------------(1)

$1/r\ d/dr(rE) = \rho i/\epsilon$ ------------(2) Poissions eqn(Gauss Law)

$\epsilon = \epsilon_r\ \epsilon_0$ ($\epsilon_0 = 8.854 \times 10^{-12}$ F/m ϵ_r = unity in practice

Prior to Corona onset $\rho i = 0$

V_0 – Potential of the wire at r_0

V = 0 – Grounds the tube at r_1

$E = V_0 / r\ln(r_1/r_0)$-------------------(3)

Ions move at drift velocity

Vi – bE (m^2/s-V) mobility

- ✓Exptl. Values available
- ✓Impurities effect 'b' (more so for non attaching gasses)
- ✓uncertain
- ✓If b_0- mobility at std. Condition.

$b = b_0 / \delta$ → (Air) Gas Density--------(4)

1 at 0^0C and 1 atm

Relative Gas Intensity :

$\delta = 273\ Pa/(T+273)$------------------(5)

Above Corona Threshold:

Inter electrode space charge << Surface Charge on electrodes then (3) is valid

Usually not satisfied in an ESP space charge density- non zero can be considered

$J_i = 2\pi r \rho_i b E$------------------(6)

per unit length

Eliminate ρi in (2) and integrate

$E = [ji/2\pi\epsilon_0 b + (r_0/r)^2 (Ec^2 - ji/2\pi\epsilon_0 b)]^{1/2}$--------(7)

Ec – (Critical) minimal E for corona at the surface of the wire ($r=r_0$))

Characteristic of Gas and wire radius independent of shape of collecting electrode if r be large and ji be high

$E = [ji/2\pi\epsilon_0 b]^{1/2}$---------(8)

Integrating (7)

$(v_0-v_1)/v_c \ \ln(r_1/r_0) = (1+\phi)^{1/2} - (1-\ln(1+(1+\phi)^{1/2})/2)$ -------(9)

V_c -> $Ec = V_c/(r_0 \ln(r_1/r_0))$-------------------(10)

$\Phi = (r_1 / Ecr_0)^2 \ ji/2\pi\epsilon_0 b$---------------------(11)

For low current $\Phi << 1$

$Ji = (8\pi\epsilon_0 b)/(r_1^2 \ln(r_1/r_0)) \ v_0(v_0-v_c)$---------------------(12)

Fig 9.4

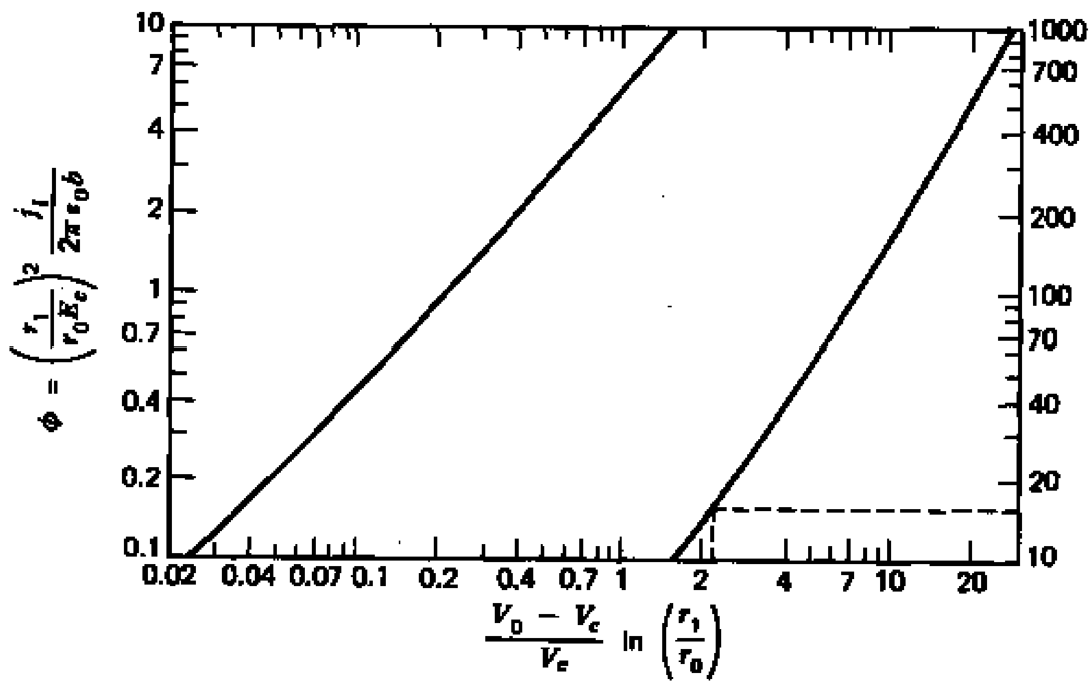
<u>Particle space charge</u>

(7) Does not include charged particles.

Low drift velocity than gas. space charge effect due to them is made dominant than the ions [near the inlet at least]

Let particle concentration be Np /m^3

Constant over a given C/S of ESP decreases with distance along down sream



10
7
4
2
1
0.7
0.4
0.2
0.1
1000
700
400
200
100
70
40
20
10
0.02 0.04 0.07 0.1 0.2 0.4 0.7 1 2 4 7 10 20
$\Phi = \left(\frac{r_1}{r_0 E_c}\right)^2 \frac{j_1}{2\pi\varepsilon_0 b}$
$\frac{V_0 - V_c}{V_c} \ln\left(\frac{r_1}{r_0}\right)$

Aerosol specific surface

$$S = 4\,\pi a^2 Np \text{--------------------} (13)$$

a – is the radius- assuming spherical particle

$\rho_i \to \rho_p$

$$P_p = E_0 PES \text{----------------------------------} (14)$$

Put in (2) and solve

$$E = [\ (r_0/r)^2(E_c{}^2+(ji/2\pi\epsilon_0 b)) + ji/(4\,\pi\epsilon_0 b(psr)^2)\ ]\ e^{2psr}$$

$$-ji/(4\,\pi\epsilon_0 b[2/psr + 1/(pSr)^2]^{1/2} \text{---------------------------} (15)$$

$$P = 2((\epsilon_p-1)/(\epsilon_p+2))+1\ ,\ 4\,\pi\epsilon_0 pEa^2 \text{----------------------------------} (C)$$

Restrict to high current region $r >> r_0$

$pSr \leq 1/10$

$$E = [ji/2\pi\epsilon_0 b\ (1+ (2pSr)/3)]^{1/2}$$

$$\approx (ji/2\pi\epsilon_0 b)^{1/2}\ (1+ (pSr)/3) \text{ ---------------(16)}$$

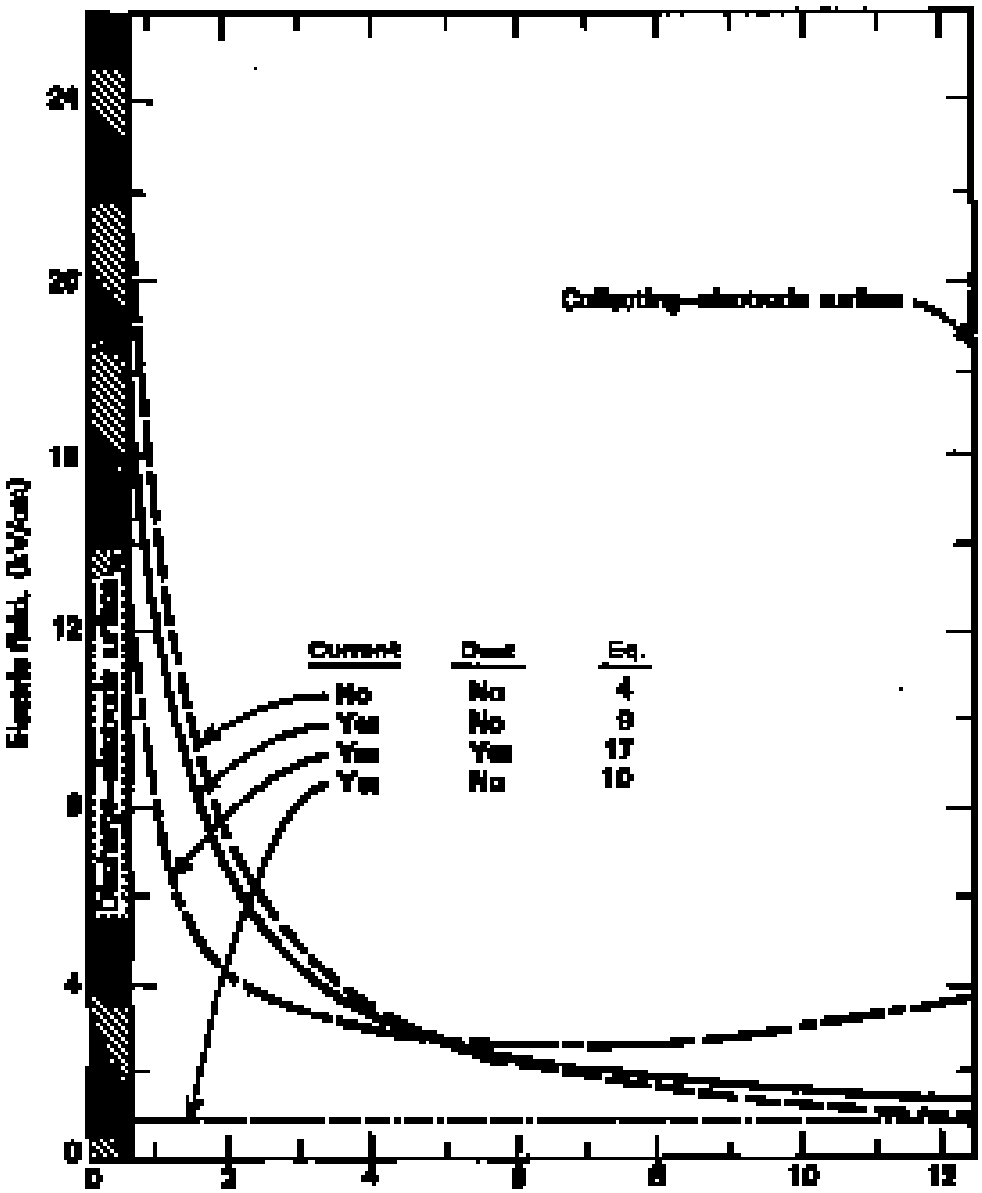
Fig 9.5

- Space Charge - reduces E near the wire

  Increases E near the tube

- With adeq. Space charge min. Does not occur at grd. electrode0

- Corona initiation Ec- Higher Voltage – in presence of space charge


Collecting-electrode surface
Current
Dust
Eq.
No No 4
Yes No 9
Yes Yes 17
Yes No 10
24
20
16
12
8
4
0
0
2
4
6
8
10
12

Particle ρ_p

Ion space – charge ρ_i

Independent of position

Poisson Equation --- upon integration =>

$$E = v_c/(r \ln (r_1/r_0)) + ((\rho_i + \rho_p) (r^2 - r_0^2))/ 2\epsilon_0 r \qquad (17)$$

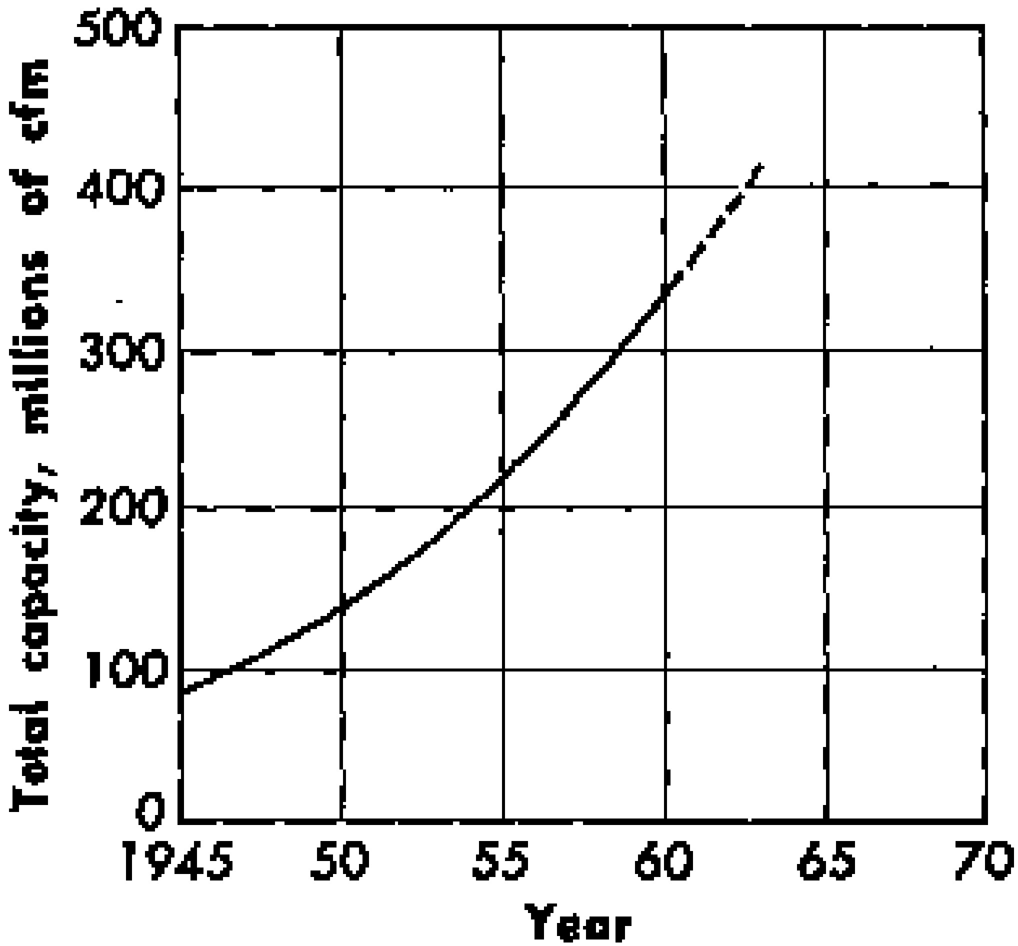
----------E in presence of space charge supplementary space charge field

$$V_0 = V_c + ((\rho_i + \rho_p)/4\epsilon_0) r_1^2 \qquad (18)$$

$$V_0 = V_c + \rho_p/ 4\epsilon_0 r_1^2 + ji \ln (r_1/r_0) / 8 \pi\epsilon_0 b_0 \qquad (19)$$

[From (6)]

$$V_c' = V_c + \rho_p/ (4\epsilon_0)r_1^2 \qquad (20)$$



Total capacity, millions of cfm
500
400
300
200
100
0
1945
50
55
60
65
70
Year

TABLE 1.1

SUMMARY OF UNITED STATES PRECIPITATOR INSTALLATIONS IN MAJOR FIELDS OF APPLICATION, 1907–1962

Application	First installation	Total number precipitators	Total gas flow, million cfm	
Electric-power industry (fly ash)	1923	880		230
Metallurgical:				57
Copper, lead, and zinc	1910	240	17	
Steel industry	1919	400	33	
Aluminum smelters	1949	100	7	
Cement industry	1911	250		34
Paper mills	1916	200		23
Chemical industry	1907	640		12
Detarring of fuel gases	1915	600		5
Carbon black	1926	50		3
Grand total		3360		364

TABLE 1.2

RANGE OF PRECIPITATOR OPERATING CONDITIONS

Gas flow	1 cfm to over 3,000,000 cfm
✓Gas temperature	to 1200°F
Gas pressure	to 150 psi
✓Gas velocity	3 to 15 ft/sec for most applications; 25 to 50 ft/sec for a few special air-cleaning units
Draft loss	0.1 in. to 0.5 in. w.g.
✓Particle size	0.1 to 200 + μ
Particle concentration	0.0001 to 100 grains/ft^3
✓Particle composition	no basic limit; solid, liquid, corrosive chemicals
✓Treatment time	1 sec to 10 sec for most applications; as low as 0.1 for a few special cases
Efficiency	most applications 80% to 99%; some 99.9 + %

TABLE 1.3

SUMMARY OF U.S. PATENTS

Collecting and discharge electrodes	100
Electrode cleaning means	50
Precipitator applications	150
Two-stage precipitators	100
Combination precipitators (electro-mechanical, electroscrubber, etc.)	100
Electrical energization	50
Details of construction	200
Miscellaneous	~250
Total for the period 1886 through 1957	~1000

Wire-Plate Geometry

- Poisson's equation for a wire-plate electrode system(Figs. 9.1b and 9.6) along the lines described earlier for the particle-free wire-tube formidable.
- Considerable simplification results, if the current is assumed to be low and that the resultant alteration of the potential by the space charge can be represented by an additive correction analogous to that in :
- $V_0 = V_c + \rho_p / 4\epsilon_0 r_1^2 + ji \ln (r_1/r_0) / 8 \pi\epsilon_0 b_0$

- It can be shown that

$$j_i = 4cj_s = (4\pi\epsilon_0 b)[V_0(V_0 - V_c)]/ (s^2 \ln(d/r_0)) \text{ --- } \quad (23)$$

Where j_s(A/m^2) is the average current density at the plate, 2c (m) is the wire-to-wire spacing, and s(m) is the wire-to-plate spacing

- The parameter d(m) is represented closely by

$$d = 4s/\pi \quad \text{for } s/c \leq 0.6 \text{-----------} (24)$$

$$d = (c/\pi)\, e^{\pi s/2c} \quad \text{for } s/c \geq 2.0 \text{-----} (25)$$

- And Fig. 9.7 for 0.6< s/c < 2.0

- The corona-starting voltage V_c in Eq.(23) is

$$V_c = r_0 E_c \ln (d/r_0) \qquad (26)$$

Where E_c is given by Eq 31.

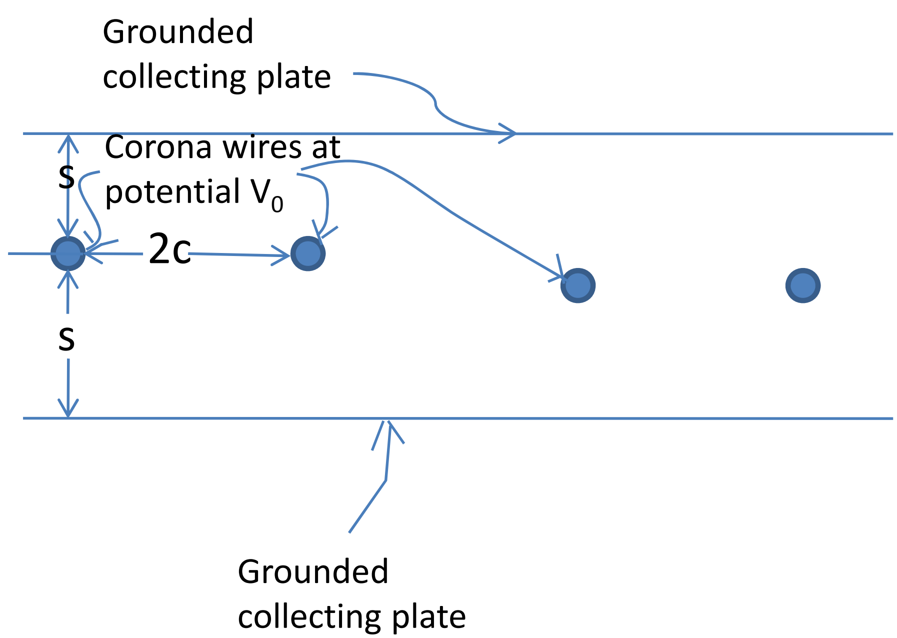


Figure 9.6 Wire-plate (duct-type) electrode arrangement

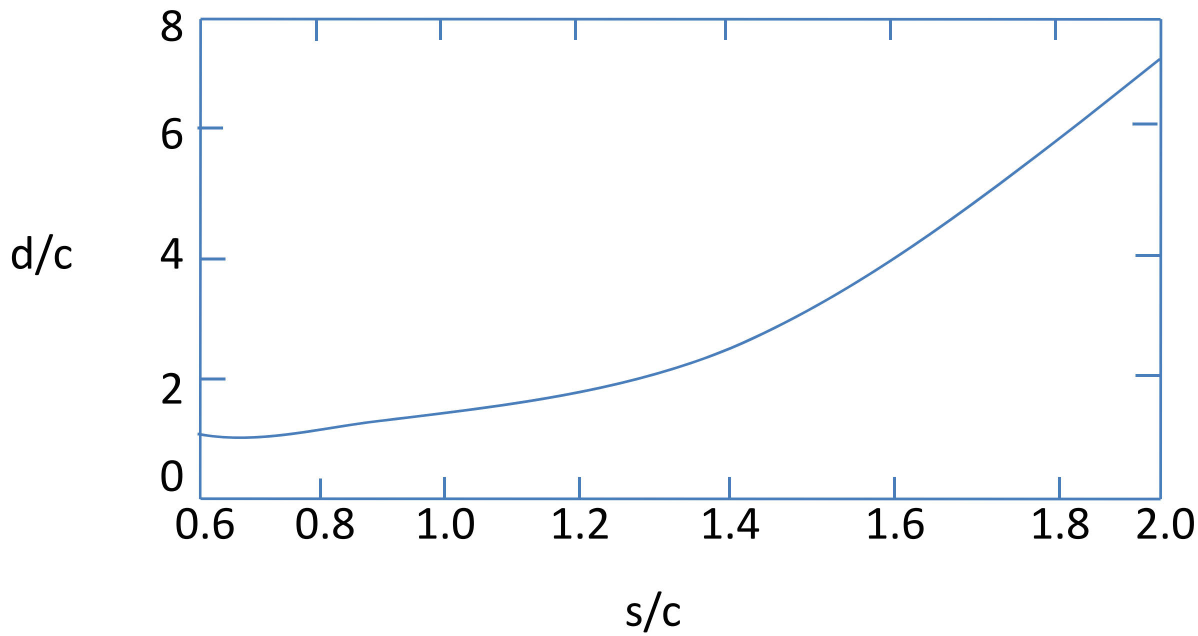


Figure 9.7 Curve for determining the parameter d in terms of the dimentions of a wire-plate precipitator (Eqs 23ff). (Used with permission of the Institute of Electrical and Electronic Engineers.)

- Consideration of the foregoing relations leads to the following conclusions:

1. As the wire-to-wire spacing increases, j_l tends to become constant.
2. There is a wire-to-wire spacing, depending on the other dimentions, for which j_s is a maximum. This comes about because reduced spacing raises the starting voltage and so tends to lower the current, but at the same time more wires are introduced between the plates, tending to raise j_s. The current maximum is broad and the associated electrode dimensions are not critical.
3. The value of j_l depends on wire-to-plate spacing inversely as a power lying between 2 and 3.

Particle space charge

- Drawing an analogy between

  $Ji = (8\pi\epsilon_0 b)\,[v_0(v_0 - v_c)]\,/(r_1^2 \ln(r_1/r_0))$ (WIRE – PIPE) and

  $j_i = 4cj_s = (4\pi\epsilon_0 b)[V_0(V_0 - V_c)]/\,(s^2 \ln(d/r_0))$ (WIRE – PLATE)

- in the latter case the ion space charge is given by the expression

  $\rho_i = [j_i \ln(d/r_0)]/(2\pi b V_0)$------(27)

- Assuming uniformly distributed particle space charge, the following relation, corresponding to

$V_0 = V_c + \rho_p / 4\epsilon_0\, r_1^2 + ji \ln(r_1/r_0) / 8\pi\epsilon_0 b_0$

- can be written as

$V_0 = V_c + (\rho_p/2\epsilon_0)s^2 + (j_l \ln(d/r_0))/(4\pi\epsilon_0 b V_0)$—(28)

- Where the apparent corona starting voltage has been raised to

$V_c' = V_c + (\rho_p s^2/2\epsilon_0)$ ------------(29)

- Comparing with

$V_c' = V_c + (\rho_p/4\epsilon_0)r_1^2$

reveals that for equal tube diameter and plate-to-plate spacing, particle space charge elevates the effective duct starting voltage twice as much as for the tube, and this increase is independent of wire-to-wire spacing.

Corona Onset and Sparkover

- In the absence of an adequate theory of breakdown in non uniform fields, it is impossible to calculate from atomic data either the corona-starting field and voltage or the spark over field and voltage.
- Furthermore, accuracy of measurement in the laboratory, and even more so in the field, is marred by surface asperities and dust deposits on the electrodes.
- Surface irregularities in combination with misaligned electrodes inevitably lower both corona-onset and spark over levels in practical installations.

- Maximum spark over voltages to be anticipated are conveniently determined in the laboratory; practical values, on the other hand, are best established through observation of similar installation.
- One indication of the un-certainities encountered is given by the empirical relation

$$V_{sn} = Vs_1 - C_1 \ln n \text{ ----------------------(30)}$$

where Vs_1 and V_{sn} are the respective spark over voltages for 1 and n wires energized by a single power supply, and C_1 is a constant.

- The physical basis of Eq. 30 becomes clear when it is remembered that

(1) the instantaneous potential of all parallel-connected wires is set by the reduced potential of whatever wire in the system is then experiencing spark-over, and

(2) the greater the total length of the precipitator, the higher is the probability of occurrence, some where in the system, of those conditions tending to lower the spark over potential.

- Attempts to compensate for poor performance by adding wires-the new wires also being fed by the original electrical set-are apt to be self-defeating.
- For effective precipitation the length of corona wire energized by a single power supply must be limited.
- It is primarily this consideration that leads to the general practice of dividing large precipitators into sections, each section energized by an independent supply.
- Table 9.1 gives rule-of-thumb values of spark-over voltage and associated variables useful for orientation purposes.
- The sparking potential coincides with the cyclic peak of the imperfectly filtered unidirectional waveform.

- Peak voltage gradients in the tabulated examples are typically of the order 4 to 6 kV/cm averaged across the inter electrode gap.
- Both corona-starting and spark-over voltages are temperature and pressure dependent.
- Electrical breakdown, whether partial(corona) or complete (sparkover), depends on the likelihood of electrons accelerating to ionizing energies in the space of a mean free path, this distance being inversely proportional to relative gas density δ.
- It has been demonstrated empirically in numerous single gases and gas mixtures that combinations of round wires and outer electrodes of arbitrary shape exhibit a corona-starting field E_c given by

$$E_c/\delta = A_g + B_g/(r_0\delta')^{1/2} \text{ -------------------------------(31)}$$

where A_g(V/m) and B_g(V/m ^{½}) are constants. The relative gas density is conventionally taken with respect to 1 atm and 25^{0}C. For air, the values

$A_g = 32.2 \times 10^5$ (V/m) and $B_g = 8.46 \times 10^4$V/m ^{½}

are recommended.

- Values for other gases are reported in the literature.
- Note that Eq. 31 is not applicable to negative corona in pure non-attaching gases, and it may grossly overestimate the negative corona-starting field at elevated pressures.

Electrical Characteristics for Common Precipitator Applications

Application	Tube Diameter or Duct Width(cm)	Sparkover voltage(kV)	Average Corona Current($mA/100\ m^2$)	Average Corona Energy Density($W\text{-}sec/m^3$)
Fly ash	20-25(duct)	40-60	10-50	100-250
Cement	20-25(duct)	40-70	7-30	150-550
Paper mill	25(duct)	70-80	7-30	100-550
Blast furnace	20(pipe)	35-45	10-60	150-400
	30(pipe)	65-75	10-30	70-400
Sulphuric acid	25(pipe)	70-100	10-40	150-900
Copper & zinc smelters, converter gas	20(duct)	40-65	10-30	~ 350
Roaster & reverberatory gas	30(duct)	~ 75	~ 10	~ 300

Example

- Determine the corona-starting voltage in room air for duct precipitator(Fig 9.6) of 9-in.plate-to-plate spacing ($2s = 0.229$ m),4-in. Wire-to-wire spacing($2c = 0.102$m), and 109-mil wire diameter($2\ r_0 = 2.77\text{x}10^{-3}$ m). Compare with a 109-mil diameter wire in a 9-in. diameter pipe.
- The duct corona- starting voltage Vc is given by Eq. 26 for which Ec, the corona-starting field at the wire, and the parameter d are required.
- Therefore, the following quantities are calculated: $\delta' = 1$;

E_c = 54.9 x 10 5 V/m(Eq 31);

s/c = 2.24;

d= 0.548(Eq. 25), and

V_c = 45.7 kV (Eq 26).

The pipe starting voltage is given by Eq.12:

$V_c = r_0 E_c \ln(r_1/r_0)$= 33.6 kV.

- For equal duct width and pipe diameter and identical wire sizes, duct starting voltage will always exceed wire-pipe starting voltage.
- Starting voltages measured in industrial precipitators are invariably lower than the calculated estimates.
- This effect is due to irregular electrode spacing and extraneous discharges from electrode asperities; in ducts, it also is attributable to the lower starting voltage of the end wires.

Power Supplies

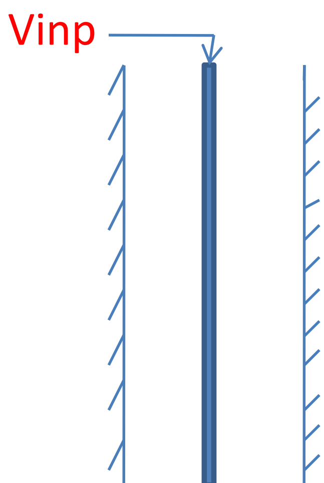
- Optimum precipitator performance requires, as a rule, the highest level of electrical energization attainable in a given set of circumstances.
- Long experience confirms that pulsating half or full-wave voltages obtained from imperfectly filtered rectifier sets yield collection efficiencies superior to those resulting from unvarying direct voltage.
- The relatively long decay periods for pulsating waveforms allow time for sparks to extinguish between current pulses, thus permitting operation at voltage and power levels not attainable in the absence of sparking.

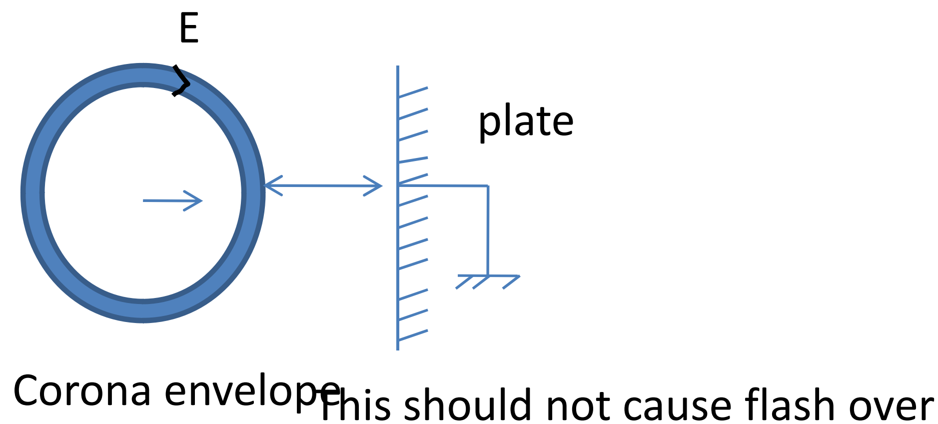
- But although sparking is general desirable in industrial practice, too frequent sparking will detrimentally lower the useful power input.
- It is mainly this consideration- the need to operate at some optimum spark rate(commonly of the order of 100 sparks per minute per electrical set)- that determines the nature of the transformer-rectifier and the associated automatic control equipment used to energize the precipitator.
- However, when spark rate provides the only feedback signal to the control system, transformers and rectifiers are likely to be vulnerable to damage from excess current. Consequently, a double-feedback system(monitoring current in addition to spark rate) is usually recommended to assure the most favourable average spark rate despite erratic variations in line and load conditions.

- Air-cleaning and sampling precipitators are run below spark over and present no control problems of consequence.
- Recent developments in precipitator power supplies and control apparatus emphasize solid-state devices (silicon and selenium rectifiers to replace vacuum tubes, thyristor controls to replace magnetic amplifiers) having advantages of improved response, lower power losses, and reduced equipment size.
- Pulse energization has been occasionally investigated, but this method has so far not shown sufficient merit to warrant commercial application.

Particle Charging

Corona Generation





Freely available electron density due to cosmic rays

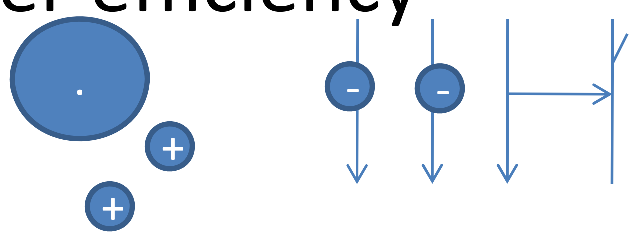
- 20 e^-/ion pairs/cc/second.
- They are accelerated by the applied voltage 'V'

and collide with particles causing ionization and hence corona- Incomplete Breakdown-forming a corona envelope. It has e^- and +ve ions.

Suppose gas contains – O_2 & SO_2- electronegative gasses.

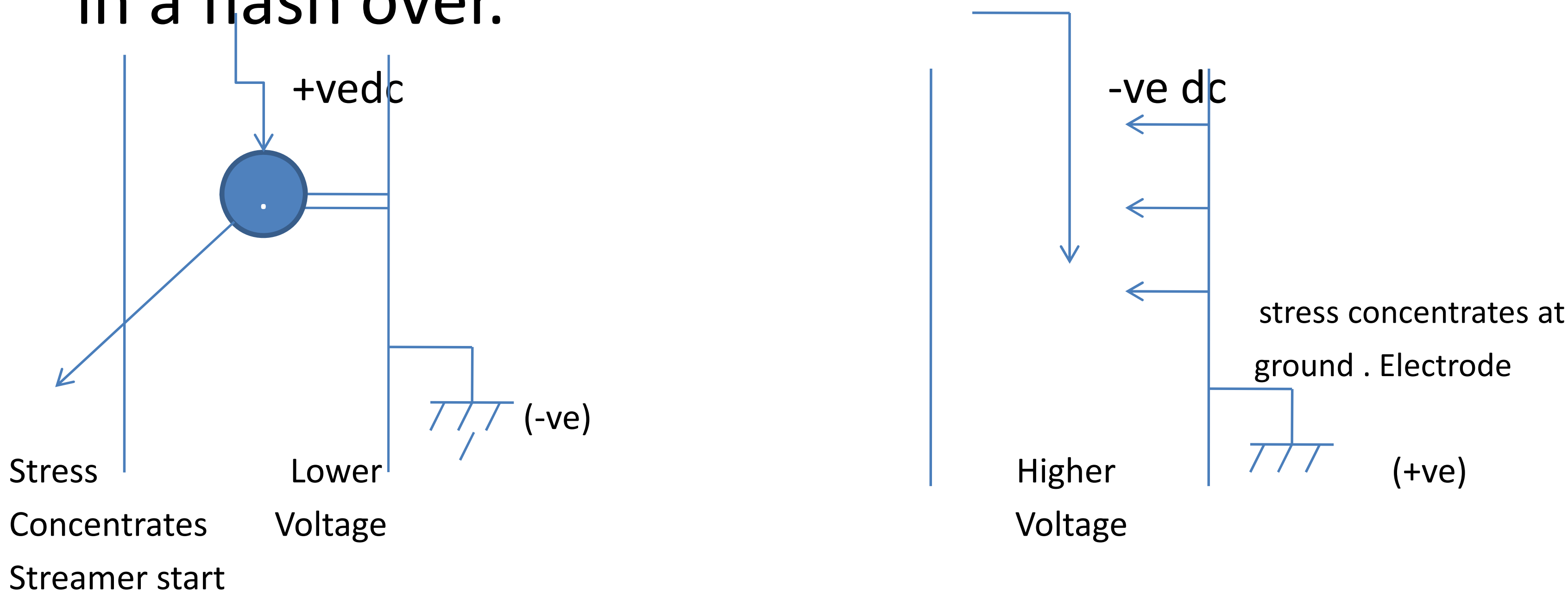
- e^- liberated get attached to neutral gas producing –ve ions. They react with solid particles and charge them –vely and move towards ground electrode.

- e^- - for particle charging require an electro-negative gas otherwise –ve corona can not be maintained.
- on the other hand +ve corona does not require an electronegative gas.
- e^- have high mobility and low mass. Mobility is 400 times that of an ion High e/m ratio gives higher efficiency



Streamer Theory

- Streamer starts from an electrode at positive potential and bridges the other electrode resulting in a flash over.



- Therefore, -ve dc permits operation at higher voltage without flashover but produces lot of ozone

- For pure Air(for health care) +ve dc charging by Induction charging is prefered.

Gas condition affects the Corona Charging

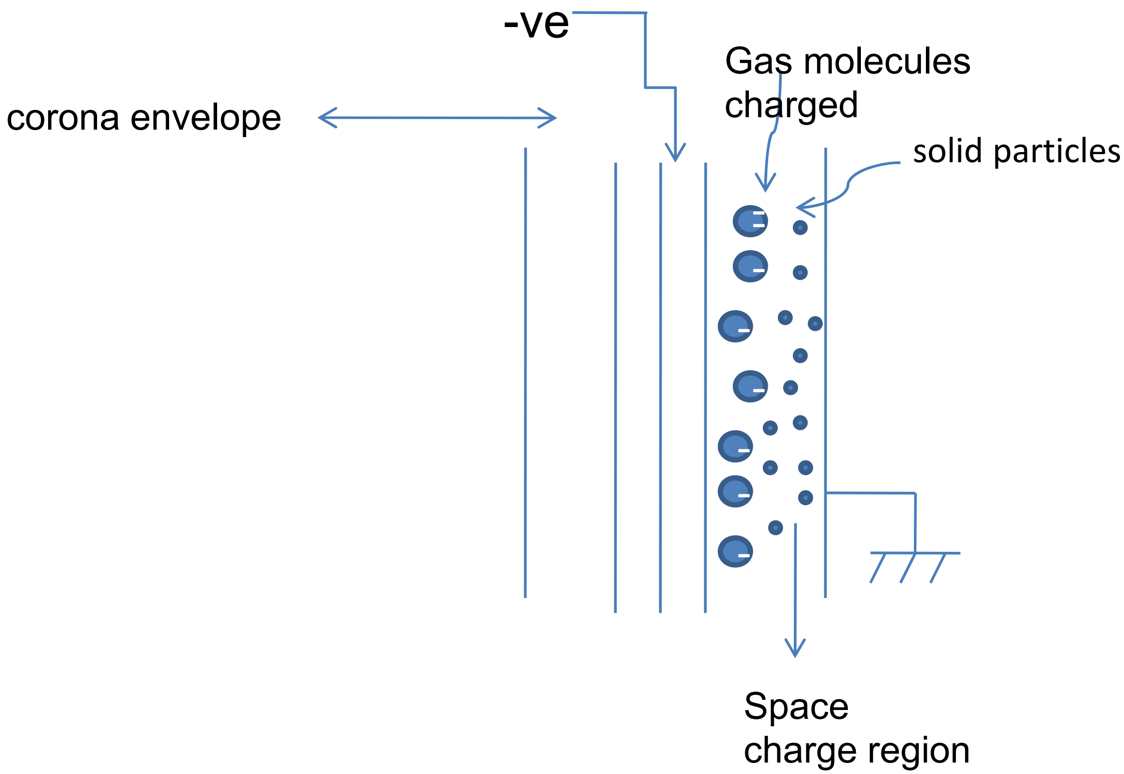
Density of the Gas, volume of gas flow-amount of dust collection. Pressure and temperature have same effect. They affect air density and hence bdv and charging voltage for corona.

E- move with a higher velocity at lower pressure(Higher temp.) less impediments and produce more secondary e^-

$\mho_{Std\ t\ \&\ p} = Vp,t/\delta$

Thus, energy available increases.

Till now consideration was that gas molecules were only there. Now effect of dust will be considered.



Effect of Dust

- As shown in the figure,there is a space charge region formed, very close to the surface of collecting electrode.Essentially consists of charged dust paticles.
- Mobility of a typical electron is 750 cm^2/volt sec where as that of oxygen ions is 1.9 cm^2/volt sec and that of charged Dust particles is 0.02 cm^2/volt sec

- Thus overall corona current is reduced.
- VI characteristics will therefore get altered from those obtained in pure gas in the lab.

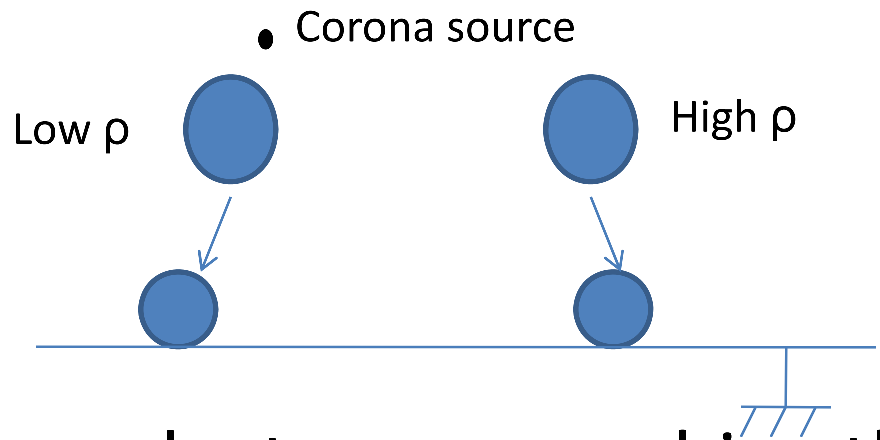
Space Charges:

1. Tries to quench the Corona.
2. Reduces the current from the source
3. Tries to stabilize the Corona current

[In its absence – spark over may occur. As a result ESP operates with little flashover]

Resistivity of the solid Particles

Next important aspect is the resistivity of solid particles Ash/cement have a high resistivity of $10^{10}\ \Omega$ cm



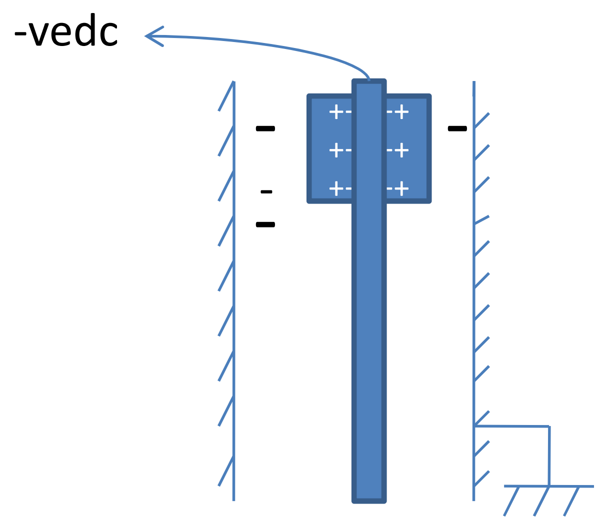
Low ρ- conductors on reaching the collector charge is released immediately.

- High e- dust particles- charged is released slowly and so may cause charge build up on the surface of the collection electrode
- Further they adhere to collection plate by image forces. It becomes difficult to dislodge. Consequently, lead to back flashover with corona source. Major Limitations of an ESP. Otherwise, ESP’s claim 99.8% efficiency.
- Coal containing high sulphur produces flyash of high resistivity>10^{12} Ω m reducing efficiency and causing back flashover.

- Dust gets collected on the corona wire also Frequent sparking is done to remove this dust clinging to corona wire.
- If the resistivity is low it increases the effective diameter of electrode –thereby necessitating higher operating voltage on the other hand high resistivity dust suppresses the corona.

Ref: DIELECTRIC PHENOMENON

by FW PEEk

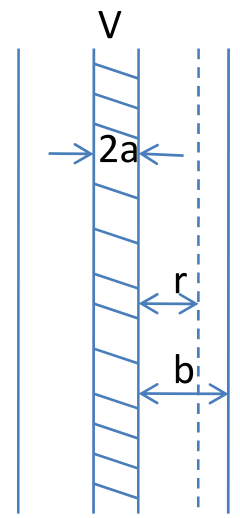


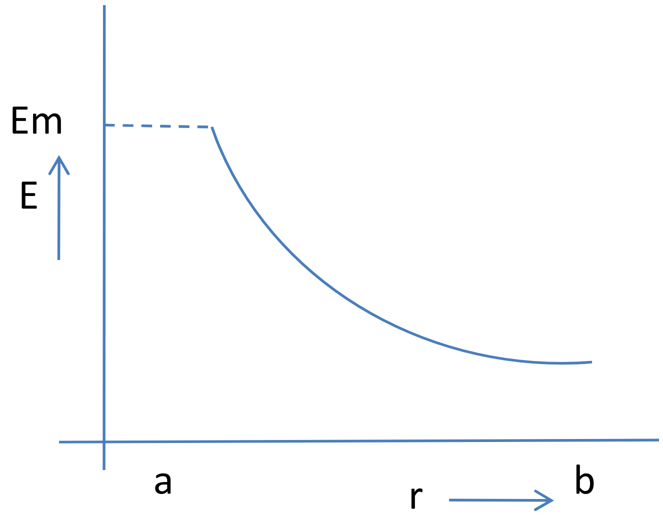
Negative Corona

- Corona starts from the roughest spot on the wire. It is localized in pulses called as Trichel pulses.
- There is a tendency to neutralize field just around the conductor by recombination.As a result entire corona disappears at Sharp points

Positive Corona: It is uniform.

PIPE TYPE PRECIPITATOR





a- Radius of Corona wire

b- radius of pipe

$E_r = V/(r \ln b/a)$..............(1)

$E_m = V/(a \ln b/a)$...............(2)

Smaller the radius of wire-higher is the gradient.

Corona initiates at a lower voltage.

Equation (2) describes the E.S field.It holds good independent of spark over/Corona in the absence pf space charege.

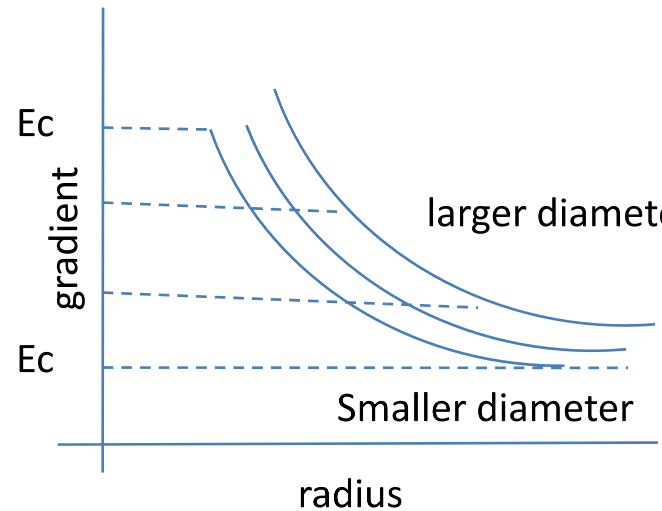
Corona inception gradient is given by

$E_c = 30md[1+0.3 \sqrt{(d/a)}]$ kv/cm(peek's formula)

m=roughness – 0.5-1 for conductors

d=relative Air density

“a” increases- Higher voltage is necessary for corona initiation.Therefore corona envelope is larger-giving more eficiency. Typically operating voltages are around 70-90 KV.



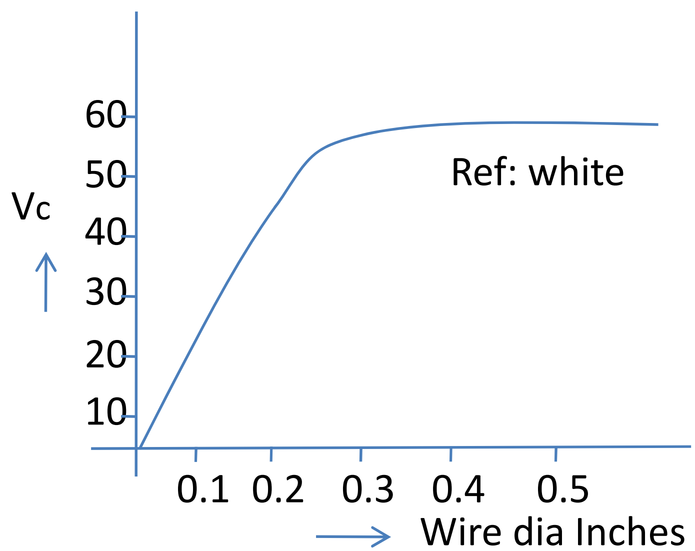
$$V_c = \int_a^b E_c \, dr = 30\, amd[1+0.3\sqrt{d/a}](\ln b/a)$$

As dia.of the wire increases $0.3\sqrt{(d/a)} << 1$

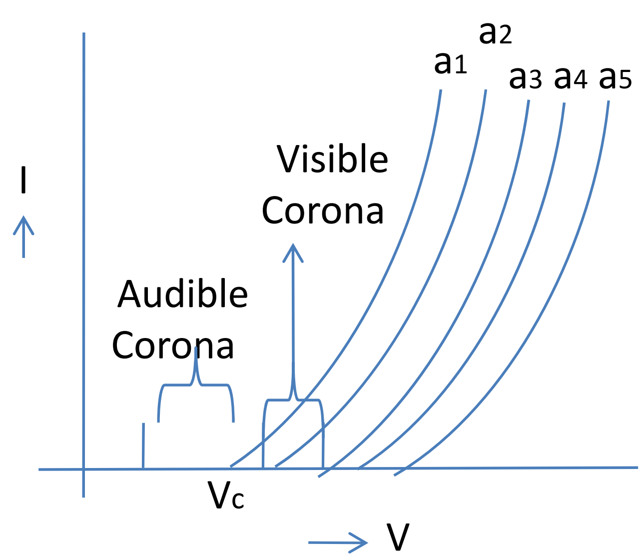
Then $E_c = 30\ md$

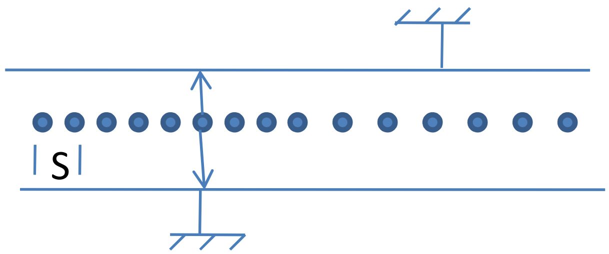
Further if the conductor is smooth & isolated

$$E_c = 30\ kV(peak)/cm$$

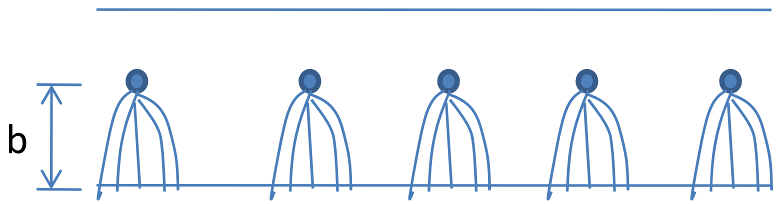


- Linear Portion is usually employed. Similar VI characteristics can be obtained for plate type precpitators. However, they are modified by spacing between wires. If the wires are very close they form an equi-potential surface. thus forming a parallel plate capacitor with uniform field.



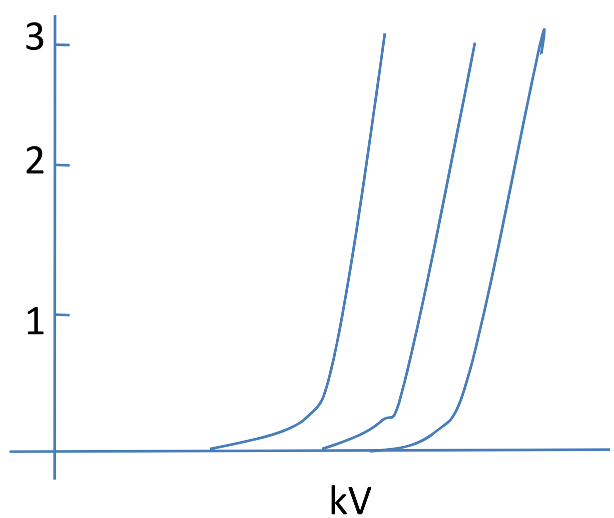


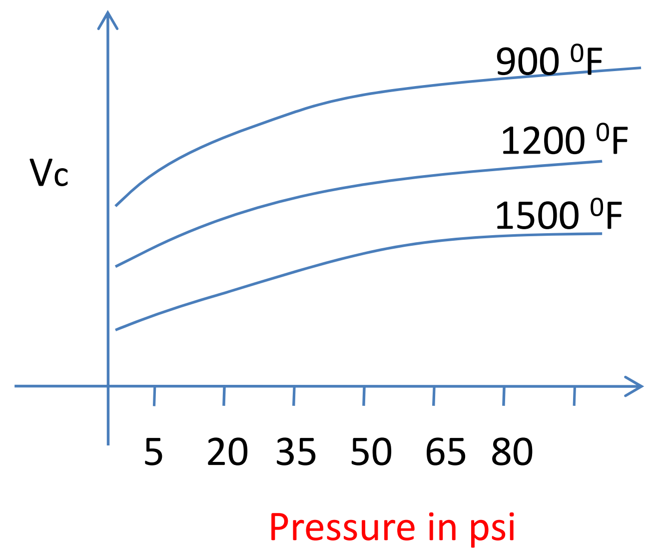
Parallel plate Cap with uniform Field



Larger spacing between wires

As 'b' is increased – Corona inception voltage increases





So far we considered how to generate the corona.

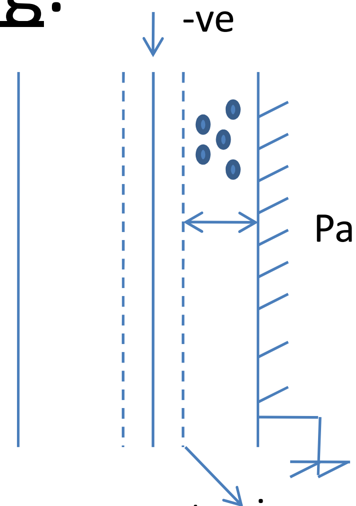
Next step is to charge the particles.

$$F = QE$$ governing equation

i. Field charging- Purely HV phenomenon requiring E.S. Field significant for particles of dia> 0.25 u

ii. Diffusion charging simultaneous electric field is there but does not require any electric field Random thermal motion of ions (analogous to pn junction) particles get charged – dia<0.1u.

Field charging:



Conducting Particles

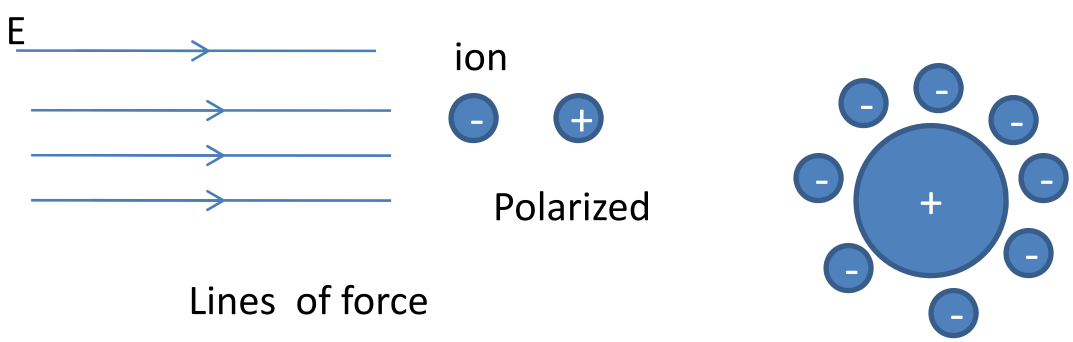
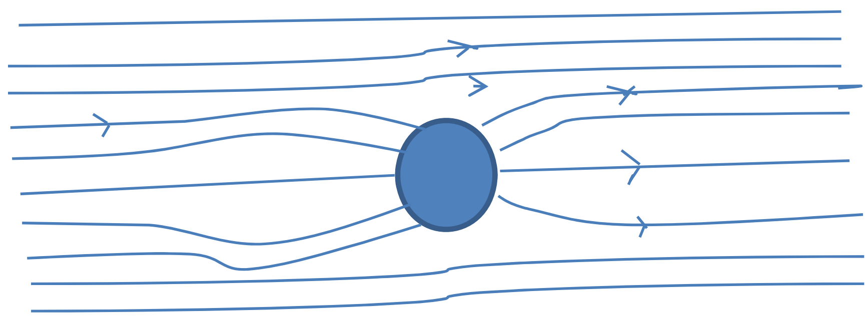
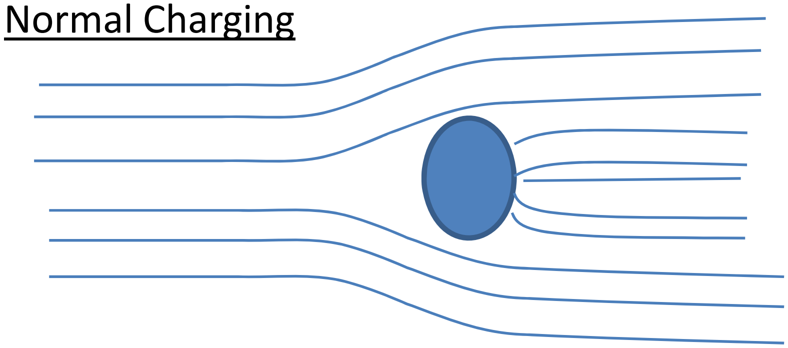


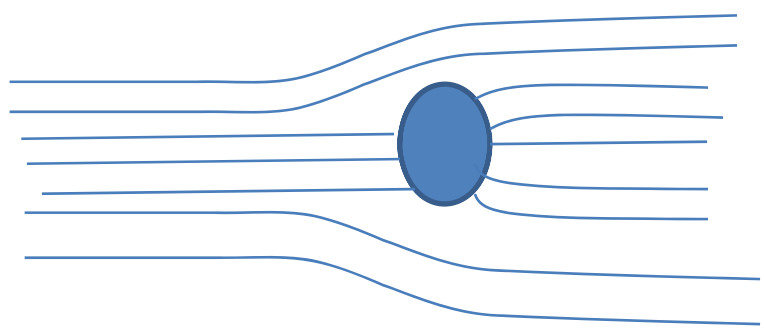
Image Forces cause attraction. Thus lead to Saturation charge density. Ions come along Field lines

Field lines modified by conducting Particle



Normal Charging





Practical case of _charging

More than the current(charging) dq/dt is important

Field charging has two components:

1. Self charge on the particle
2. Charge due to Corona wire- modified by the particle

Self charged field

$E_{resultant} = 3\ E_0 \cos \theta - qx1/(4\ \pi\ \epsilon_0 a^2)$

radius →

Applied Field as modified by the particle

Particle assumed to be spherical

$I = dq/dt = \text{Rate of charging} = \int_0^{\theta} J dA$

$= \int [N_0 e \mu E] dE$

→ Ion charge

No.- No. of charging ions with μ mobility when charge is saturated(i.e., maximum)

$$E = 3E_0 \cos\theta - q/(4\pi\epsilon_0 a^2)$$

Should be zero i.e., E=0 and θ=0

$\Rightarrow \cos\theta = 1$

$$3E_0 = q_s/(4\pi\epsilon_0 a^2)$$

$\Rightarrow q_s = 12\pi\epsilon_0 a^2 E_0$

- Max. charge on a single particle.
- For a conducting particle voltage must be as high as possible so that charge density is proportional to charging voltage

Diffusion Charging

- Due to normal temperature in a normal gas there is a thermal velocity/agitation
- At about 600°F there is turbulence, leads to thermal ionization.
- This establishes ions in random motion hitting the particles in the agitating gas.
- Thus diffusion becomes important.
- In a practical ESP we have a combination of field & diffusion-charging

Particle collection

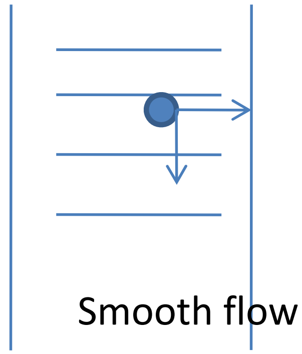
Forces:

1. ES FORCE $F_E = qE$
2. Gravitational $F_g = mg$
3. Inertial force $F_i = m dv/dt$ v - velocity of medium
4. Viscous force $F_n = 6\pi a \eta v$

Particle diameter viscosity of medium

Motion of particle follows Newtons laws of motion

For particle sizes 0.10-0.15 u Fg is negligible



Assume that particle is suspended in the medium.

Fe - Fi – Fn=0

qE -m dv/dt – 6πaηv =0

$$v = w = qE\ [1-\varepsilon^{(-6\pi a n t/m)}]\ /(\ 6\pi a \eta)$$

↓ Migration velocity

Trade Secret – Efficiency of a precipitation

$T = m/(6an\pi)$ (Time constant of the precipitation)

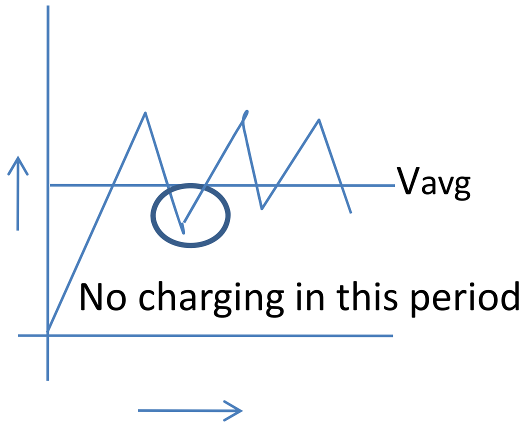
Typical value – $1.23 \times 10^{-5} \times a^2$ seconds

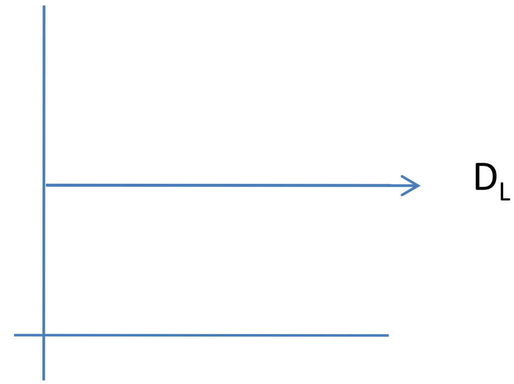
Normally in the range of particles collected exponential terms are negligible

$$w = qE/(6\pi a n)$$

[Ref: Anderson Deutch]

Particle charging assumed that corona is dc. But in practice we have rectified ac(HW or FW) without a filter cap.





Waveform is some what raw toothed. Charging is in bursts [disadvantage] overall charging time high eg:

Const. dc t_{dc}=0.35 s - length of ESP= 1m to 4 m

Ripple – tripple = 1.17 s

reach saturation charge

However Q_{max} depends on peak value of voltage as in a capacitor.

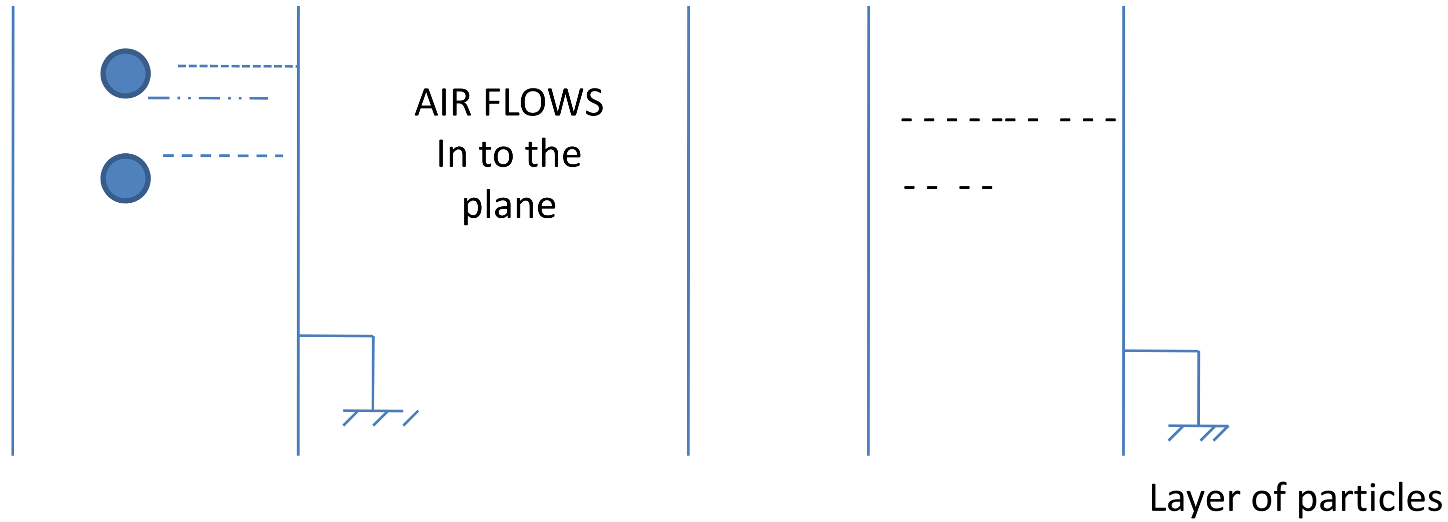
Q_{max} ripple>> Q_{max}(dc average)

Peak/average = 1.43 to 1.63

$I = KV^n$ $n>1$

Higher corona current obtained with small change in voltage

Efficiency depends on the size of the particle



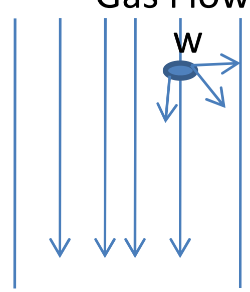
Factors affecting Efficiency:

1. Agglomeration of the particles
2. Reentrainment
3. Back corona

Rapping is done to remove the particles that are collected on the collection electrode. Some of it re-enters the system.

It was considered that particle is suspended, but in reality it is being moved by the gas.

Gas Flow in the Precipitator



1) Laminar

$$V_{max} = 2V_{average}$$