ELECTROSTATIC PRECIPITATORS

Electrostatic precipitators work by charging particles, then collecting the charged particles in an electric field.

Particle Charging

Charging occurs by two mechanisms: diffusion charging and field charging. In diffusion charging, ions in the gas bounce around due to Brownian motion, bump into a particle, and transfer their charge to it. The number of charges that a particle acquires due to diffusion charging is given by

$$n(t) = \frac{d\,k\,T}{2\,K_E\,e^2} \ln\left[1 + \frac{\pi\,K_E\,d\,\bar{c}_i\,e^2\,N_i\,t}{2\,k\,T}\right] \tag{1}$$

where:

$n(t)$	is the number of charges acquired by diffusion charging in time t,
d	is particle diameter,
k	is Boltzmann's constant,
T	is absolute temperature,
K_E	is the electrostatic constant, = $4\,\pi\,\varepsilon_o$
e	is the charge per electron,
$\bar{c}_i$	is the mean thermal velocity of the ions,
N_i	is ion concentration, and
t	is time.

Equation (1) shows that the number of charges that a particle acquires by diffusion increases with particle size and with time.

Field charging occurs when a particle is located within an electric field that contains ions. The ions will travel along the electric field lines. The presence of the particle will disrupt the electric field somewhat. If the particle holds relatively little charge, the electric field lines will tend to flow through the particle and in that case ions that flow along the field lines will contact the particle and transfer their charge to it. As the particle becomes charged, the electric field lines will be repelled from the particle and field charging will no longer occur. At that point, the particle has attained its saturation field charge. The number of charges that a particle receives due to field charging is given by

$$n(t) = \frac{3\,\varepsilon}{\varepsilon + 2}\left(\frac{E\,d^2}{4\,K_E\,e}\right)\left[\frac{\pi\,K_E\,e\,Z_i\,N_i\,t}{1 + \pi\,K_E\,e\,Z_i\,N_i\,t}\right] \tag{2}$$

where the terms are as above, and

ε is the dielectric constant of the particle, and
Z_i is the mobility of the ions.

For further information about evaluation of some terms in Equations (1) and (2), see Hinds (1999). Whereas diffusion charging is particularly important for small particles and for short charging times, field charging is particularly important for large particles and long charging times.

For a particle immersed in ions within an electric field, as happens in an electrostatic precipitator, the total number of electrical charges it acquires can be taken as the sum of those from diffusion charging and those from field charging. As a practical matter, in many electrostatic precipitators the particles of concern are large enough and the charging period is long enough that diffusion charging is relatively unimportant. Further, inspection of Equation (2) shows that the time-dependant, bracketed term approaches unity as time increases. In this situation, the number of charges that a particle acquires is approximately

$$n(t) \approx \frac{3\varepsilon}{\varepsilon+2}\left(\frac{E\,d^2}{4K_E\,e}\right) \quad . \tag{3}$$

Equation (3) gives the saturation field charge for the particle.

Corona Discharge

The discussion above presumes that ions are present in a high concentration. In an electrostatic precipitator, these ions are produced by a corona discharge. Gas molecules ionize naturally, due to impact from cosmic rays. The resultant ion pairs recombine over time, due to their electrostatic attraction for each other. In a high electric field, these ionization pairs accelerate due to the field and collide with other gas molecules. If the electric field strength is high enough, these collisions form further ion pairs that then accelerate to collide and form more ions in a cascading process called “corona discharge”

In a non-uniform electric field, this cascade will continue in regions where the electric field strength exceeds a threshold value. For example, the electric field strength is high around a charged wire in a grounded tube. If the voltage applied to the wire is high enough, a glow can be seen at its tip; this glow is in the region of corona discharge. If voltage is applied to two parallel plates, forming a uniform electric field, no corona will form until the electric field is high enough to cause a spark between the plates.

Particle Collection

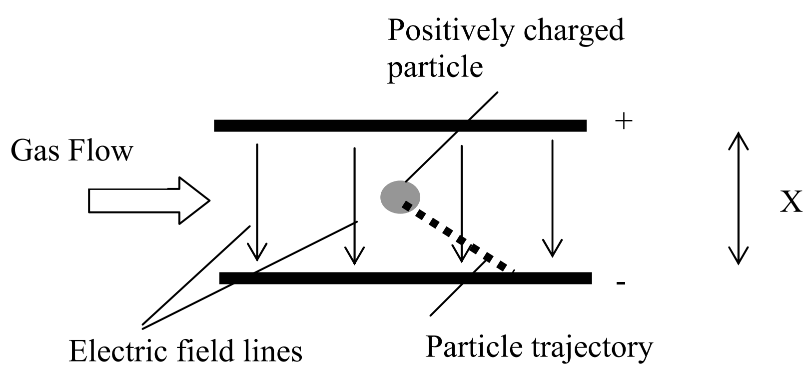
A balance between the forces of electrostatic attraction and Stokes’s Law drag yields the following equation for the velocity of a particle in an electric field.

$$W = \frac{n\,e\,E\,C_c}{3\pi\mu d} \tag{4}$$

where

W	is the particle migration velocity due to electrostatic force,
C_c	is the slip correction factor,
E	is the electric field strength in the collection region
μ	is gas viscosity

Equations (1), (2) and (4), or Equations (3) and (4) can be combined to determine the particle migration velocity, W.



If gas flows through a channel that is perpendicular to an electric field as shown in the diagram above, the fraction of particles that reaches the surface of the collecting electrode and is removed from the gas stream is:

$$\eta = 1 - \exp\left(- \frac{W\,t}{X} \right) \tag{5}$$

where

t	is the time the particle spends in the electric field, and
X	is the width of the channel, measured in the direction of the electric field.

Equation (5) can be rearranged to give

$$\eta = 1 - \exp\left(- \frac{W\,A}{Q} \right) \tag{6}$$

where

A	is the total surface of the collecting plates, and
Q	is the volumetric gas flow through the precipitator

Equation (6) is called the Deutsch-Anderson equation and finds wide use in models for the performance of electrostatic precipitators. Equation (6) describes the ideal behavior of a precipitator. As a practical matter, the calculation of W using the equations above is inexact.

Equation (6) is sometimes used in reverse, to determine values of electrical migration velocity for precipitators where efficiency and specific collection area are known.

Sometimes the term A/Q is grouped to form a term called the "specific collection area", expressed in units of ft^2/1000 cfm or sometimes in units of cm/s. A typical value of the "specific collection area" for an industrial precipitator might be 500 cfm/1000 ft^2.

References

Hinds, William, Aerosol Technology, Wiley, New York, 1999.

White, Harry J., Industrial Electrostatic Precipitation, Addison Wesley, Reading MA, 1963.

Note: The book by White is a classic and although no longer in print or readily available, does contain a wealth of information. No better book has been published since on the general topic of practical electrostatic collection.