FUNDAMENTAL MECHANISMS OF ELECTROSTATIC DEDUSTING - DIFFUSION CHARGING OF PARTICLES IN ELECTROFILTERS

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ABSTRACT: The technological process of electrofilters involves several physical mechanisms which are interrelated. In many cases, in practice, the removal of the collected particle layer from the collecting surface presents serious problems as the removal methods reintroduce the collected material back into the gas stream, reducing the collection efficiency. In practice other effects that reduce the collection efficiency arenon-uniform gas velocity distribution, bypassing of electrized regions by particle-loaded gas parts and re-entrainment of particles during periods when the collected material is not removed.

KEY WORDS: corona effect, electrofilters, dedusting, electrodes.

1. INTRODUCTION

In many applications, the flue gas environment and fly ash composition are such that the collected particle layer limits the maximum values of useful voltage and current.

Due to the inherent complexities associated with the electrofilter technological process and the difficulty of justifying the limitations to practical applications, the development of a fundamental model that adequately describes the electrostatic deposition process is a formidable problem. [2]

To separate particles from a two-phase medium using an electrofilter, the following operations are required:

- electrical charging of particles in the biphasic medium;
- moving dust particles towards the deposition electrodes;
- separation of particles on the deposition electrodes;
- removal of material from the deposition electrodes for discharge outside the electrofilter.

Each electrofilters consists of two main parts: the collecting chamber, through which the gas stream to be cleaned passes, and the electrical equipment supplying this chamber with high-voltage DC. Inside the chamber are the main elements of the installation: the deposition electrodes and the emission (corona) electrodes.

2. CORONA DISCHARGE IN DC VOLTAGE

Corona discharge is an autonomous and incomplete discharge that occurs at a certain potential difference applied to an electrode of small curvature only in a limited area around it (corona discharge layer).

The phenomenology of unipolar DC voltage Corona discharge depends on the voltage polarity. [2, 5]

The deposition electrodes are profiled or smooth, large-area, profiled or smooth plates on which the dust is deposited. The deposition electrodes are always placed vertically, at a constant distance from each other, called the electrode pitch (200 - 400 mm). The corona electrodes, suspended on supporting frames, are mounted in the axis between neighboring collecting surfaces. A high DC voltage is applied to these electrodes, which is produced by the transformer-regulator power supply unit. [5]

Dust particles in the raw gas become electrically charged by moving towards the opposite pole. The dust remains on the electrodes until the electrodes are shaken, when it falls into the collector hopper, from where it is discharged to the outside.
Corona discharge is the phenomenon that makes the electrofilter work, because this mechanism forms the ions that electrically charge the particles.
A stable discharge requires two electrodes, one with a radius of curvature much smaller than the other. The distance between the electrodes must be much greater than the radius of the smaller one. Depending on the polarity of the emitting electrode, the corona discharge can be negative or positive.
Industrial electrofilters use negative polarity on the emitting electrode because high voltages can be applied without short-circuiting between the electrodes. The electrical potential at which the discharge is initialized is called the breakdown or threshold potential.
The exact value depends on the geometry of the emission electrode, the distance between the electrodes and the nature of the gas.
A corona discharge is realized in a plasma zone and a unipolar ionic zone.
The ionization process takes place only in the plasma zone. Outside this region, the electric field is not strong enough for ionization and the unipolar ions are directed by the electric force towards the deposition electrode - Figure 1.

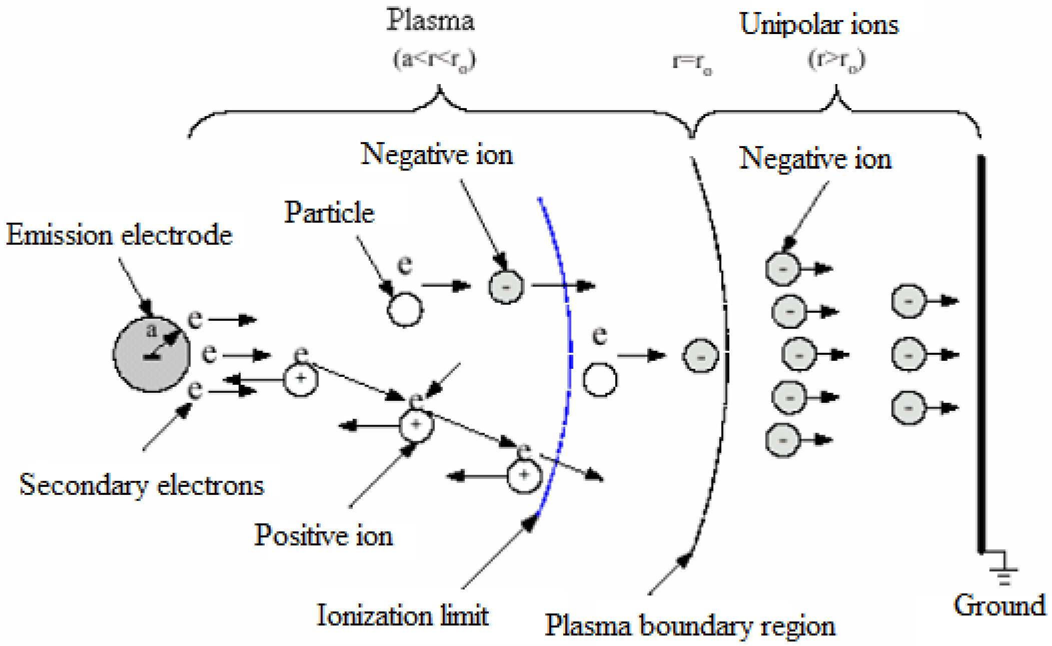

Figure 1. Corona discharge

Negative corona discharge is only possible in electronegative gases such as oxygen, CO2, water vapor. It does not occur in gases like nitrogen, hydrogen, helium, argon which have no affinity for electrons. [5]
Electrons needed to initiate the process are produced by ionization. They are repelled and accelerated outwards by the electric field. Collisions between electrons and neutral gas molecules produce several positive electron-ion pairs in a self-sustaining process called electron avalanche. The secondary electrons that maintain the discharge are generated by the photoemission of the electrode. Free electrons attach to solid particles and form negative ions.
At very high voltage, the main region of the electrofilter can be represented by a two-dimensional model because the ion discharge is uniform across the electrode.

3. DIFFUSION CHARGING OF PARTICLES IN ELECTROFILTERS

In order to explain the process of electric charge loading, only spherical particles will be considered. The uptake of negative ions (produced inside electrostatic precipitators by negative corona discharges) by such a particle can follow two distinct processes, one of which is due to the phenomenon of thermal agitation, a negative ion can accumulate a kinetic energy high enough so that it can reach the surface of a particle - charge by diffusion. This mechanism is important for very small particles (diameters less than 0.1 μm). [3, 4]
The mechanism of charge by diffusion refers to the charge accumulated by particles even if the applied electric field is very small or even zero, and even if the particle diameters are extremely small (equivalent to a few mean free paths of ions in air). This mechanism depends on the probability of collision between particles and ions animated by random motion or their thermal kinetic energy (Brownian motion).
In the absence of electric field, the ion distribution is uniform around the particles and each surface element has an equal probability of collision. With diffusive charging, the amount of charge accumulated depends on the diameters of the particles, the ion density, the average thermal velocity of the ions, the dielectric constant of the particles, and the time the particles are in the field. [3, 4]
White proposes a law of particle charge by diffusion as a function of the rate of thermal agitation and the concentration of ions, as well as the temperature of the medium considered. Gas kinetic theory shows that the density of a gas considered in a potential field (e.g. in an electric field given by a potential difference) is not uniform and is described by the following relation:

$$N = N_0 \cdot e^{\frac{\Delta V}{kT}} \quad \textbf{(1)}$$

If a particle is in an ionized gas, taking the electric charge of the particle to be $(n \cdot e)$, the potential energy of an ion at a distance r from the particle is expressed by the following relation:

$$\Delta V = -\frac{1}{4 \cdot \pi \cdot \varepsilon_0} \cdot \frac{n \cdot e^2}{r} \quad \textbf{(2)}$$

which is the energy required to bring the ion from infinity (where the potential is considered to be zero) to the point at distance r from the particle.
The ion density at the surface of the particle can be written as:

$$n_i = n_{i0} \cdot e^{-n \cdot e / 4\pi\varepsilon \cdot a \cdot k \cdot T} \quad \textbf{(3)}$$

According to the kinetic theory of gases, the number of ions hitting the particle surface is given by the relation:

$$\frac{d\varphi}{dt} = \frac{n_i \cdot v}{4} \cdot (4 \cdot \pi \cdot a) \quad \textbf{(4)}$$

If it is assumed that all ions that collide with the particle's surface are trapped, the following expression for the charge accumulated by a particle is obtained by integration from relations 3 and 4:

$$q = \frac{a \cdot k \cdot T}{e^2} \log\left(1 + \frac{t}{\tau}\right) \quad \textbf{(5)}$$

where, the characteristic charging time τ is given by the relation:

$$\tau = \frac{k \cdot T}{\pi \cdot a \cdot v \cdot n_{i0} \cdot e^2} \quad \textbf{(6)}$$

Liu and Pui proposed a different formulation for describing the velocity of electric charge charge charge by diffusion of a particle. The specialists suggest that the distribution of ions around a particle does not follow the Boltzman distribution, but comes from the flow of j ions traveling towards it:

$$j = -4 \cdot \pi \cdot r^2 \cdot \left[D \cdot \frac{dn_i}{dr} - \mu \cdot E \cdot n_i \right] \quad \textbf{(7)}$$

where D is the diffusion coefficient. Expressing the diffusion coefficient by Einstein's relation:

$$D = \frac{k \cdot T}{e} \cdot \mu \qquad \textbf{(8)}$$

the ion flux j can be written as:

$$j = -4 \cdot \pi \cdot r^2 \cdot D\left[\frac{dn_i}{dr} - \frac{e}{k \cdot T} \cdot E \cdot n_i\right] \qquad \textbf{(9)}$$

In the stationary regime, the ion flux j is constant and independent of the point under consideration (of r). Putting the boundary condition $n_i = n_{i0}$ when $r \to \infty$ (the concentration of ions at a sufficiently large distance from the particle can be considered as not influenced by the presence of the particle), the following expression for the calculation of n_i is obtained:

$$n_i = \exp\left(\frac{-e \cdot \Delta V}{k \cdot T}\right) \cdot \left[n_{io} + \frac{j}{4 \cdot \pi \cdot D} \cdot \int_r^{\infty} \frac{1}{r^2} \cdot \exp\left(\frac{e \cdot \Delta V}{k \cdot T}\right) \cdot dr\right] \qquad \textbf{(10)}$$

Specialists use an expression for the electric potential by considering the Coulomb force and the force given by the electric image of the ion on the particle surface:

$$\Delta V = \frac{n \cdot e^2}{4 \cdot \pi \cdot \varepsilon_0 \cdot r} - \frac{\varepsilon_r - 1}{\varepsilon_r + 1} \cdot \frac{e \cdot a^3}{2 \cdot r^2 \cdot \left(r^2 - a^2\right)} \qquad \textbf{(11)}$$

With the expression for the ion concentration and the electric potential known, the calculations proceed as in White's theory. The comparison of the results obtained by the two methods leads to the conclusion that, for fine particles (0.05<a<0.12 μm), the difference between the theoretical results and the experimental measurements are approximately the same for White's theory and the one developed by Liu and Pui. For larger particle sizes (a>0.28 μm), the second theory shows better agreement between theoretical and experimental results.

4. DISPOSAL OF COLLECTED MATERIAL

In dry deposition, the removal of the collected material from the collection plates and the material transport devices from the electrofilter are fundamental steps in the deposition process. These steps are fundamental because the collected material must be removed from the electrofilter and because excessive build-up of thick layers on the plates must be avoided to ensure optimal operating conditions.

The material deposited on the collection plates is usually dislodged mechanically or by vibrating the plates, a process called shaking. The dislodged material falls by gravitational force into bunkers under the plates and is removed from the electrofilters.

The effect of shaking on the collection process is primarily determined by the intensity and frequency of the force applied to the plates. Ideally, the shaking intensity should be high enough to remove a significant portion of the collected material, but not so high as to push the material back into the main gas stream. [3, 4]

The shaking frequency should be adjusted so that a thicker layer can be removed between shakes more easily without degrading the electrical conditions. In practice the optimum shaking intensity and frequency should be determined experimentally. In the case of perfect shaking, the collected layer of material would not be re-entrained, would not migrate down towards the collection plate by sliding, would be held by the electrical forces and allowed to fall due to the shaking forces.

Currently, there are no models that adequately allow for the distribution of acceleration on the deposition electrodes due to the shaking force as well as the magnitude and direction of acceleration required to remove a layer with certain physical and electrical properties. Such models are necessary for the improvement of shaking systems. There is also a need for models to predict the effects of shaking on the performance of the electrofilter and to predict the particle size and concentration distribution of the reentrained material. Currently the effects on the performance of the electrofilter due to reentrainment by shaking down are predicted empirically based on on-site measurements.

5. LIMITING FACTORS AFFECTING ELECTROFILTER PERFORMANCE

The performance of an electrofilter with good mechanical and structural characteristics will be determined primarily by the electrical operating conditions.

Any limits of applied voltage and current density will reflect on the optimum collection efficiency that can be achieved. The electrofilter should not be operated at the highest usable values of applied voltage and current density for the following reasons:

- high applied voltages produce high electric fields,
- high electric fields produce high saturation values and limited charges that a particle can acquire,
- high current densities produce high rates at which particles charge up to saturation or limiting charge values,
- high current densities produce an increased electric field near the deposition electrode due to the contribution of the "ionic charge of space" to the field,
- high electric field values and particle charging produce high migration velocities and decrease particle transport to the deposition electrode.

The electrical conditions in an electrofilter are limited either by the electric breakthrough of the gas in the space between the electrodes or by the electric breakthrough of the gas in the collected particle layer. [1]

If the electric field in the space between the electrodes is high enough, gas breakthrough will be evidenced by a spark propagating in the space between the electrodes. The applied operating voltage and current density will be limited by these spark conditions.

If there is a layer of particles on a deposition electrode, a corona current will flow through the particle layer to the grounded deposition electrode.

The average electric field in the particle layer can increase to the point where the gas in the interstitial space is electrically pierced. This piercing results from the acceleration of free electrons to ionization velocity to produce an avalanche state similar to that at the corona electrode.

The electrical breakthrough resistance is also influenced by the size of the particles collected by changing the volume of the interstices. It has also been found that the puncture resistance varies with particle resistivity, with high puncture resistance being associated with high resistivity. [1, 2]

6. CONCLUSION

To keep collection efficiency as high as possible under difficult operating conditions, and increasingly advanced personal computer controlled control units and/or programmable logic controllers are used.

Filtration performance can be improved by applying the following measures:

- increasing the distance between emission and deposition electrodes from 300 mm to 400 mm;
- increasing the supply voltage from 78 kV to 110 kV;
- use of new, more efficient emission electrodes;
- complete automation of the dust separation process in the electrostatic precipitator.

One of the main objectives of the automatic control units is to keep the voltage in the electrofilter section as close as possible to the electrical discharge.

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