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Plate Type Electrostatic Precipitator Essentials & Issues for Optimising Overall Efficiency

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Abstract: Electrostatic Precipitator, in this paper, we will discuss about primary details and general information related to plate type ESP's. Later their importance and why they should be installed replacing traditional filters. Why and whereabouts of ESP's like flow dynamics, flow analysis shall be figured out. We shall study about the factors that affect the design and performance of the ESP's. On the same track, their performance based values generated in openFOAM and ANSYS. It is interesting to find that all parameters cannot be set to its optimal performance without compromising few ones.

Keywords: *Plate - ESP, flow dynamics, flow analysis, ANSYS, openFOAM, operating characteristics, performance.*

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I. Introduction

ESP, generally abbreviated as 'Electrostatic Precipitator' is the most cost effective filtering device for various industry process. They can be found almost everywhere at places where gaseous emissions are present and the requirement of filtering arises. ESP, in general can be understood as separation of particles using a simple principle of charge separation. This charge is provided by large electrode plates installed within the filtering system. These electrode plates are powered up during operations and later during operations, provide a charge to the particles. Heavy particles stay down and light particles which are clean is nature, are blown out through the chimney. All this comes with a cost of installation and proper application without compromising the performance. This is what we would be doing in this paper.

II. Primary Details about Electrostatic Precipitator & Where it all started

It all started when a patent was registered for a device that charged the particle, and later would be separated by ESP's. This patent was filed by Prof. Cottrell, a chemistry professor. To start with ESP, it is essential to know the basic components. Depending upon the component used, there can be different types of precipitators are in use today. Let's start with plate type precipitator. Its construction consists of number of plates placed at a space between 1 to 20 centimetres, also, a thin set of wires placed between the gaps. The gas is allowed to pass through the space between the plate. For the operation, when a high negative voltage is applied between wires and plate, an electric corona discharge ionises the gas around the electrode. Negative ions flow to the plates and charge the gas flow particles. These are collected on the grounded plates in the form of a layer. Precipitator performance is extremely sensitive to two particulate properties viz electrical resistivity; and particle size distribution. Since relatively low applied voltage is used and no sulphuric acid vapour is present, the values obtained indicate the maximum ash resistivity.

III. Responsible Factor- Electrical Resistivity

In an ESP, where particle charging and discharging are key functions, resistivity is an important factor that significantly affects collection efficiency. While resistivity is an important phenomenon in the inter-electrode region where most particle charging takes place, it has a particularly important effect on the dust layer at the collection electrode where discharging occurs. Particles that exhibit high resistivity are difficult to charge. But once charged, they do not readily give up their acquired charge on arrival at the collection electrode. On the other hand, particles with low resistivity easily become charged and readily release their charge to the grounded collection plate. Both extremes in resistivity disturb the efficient functioning of ESPs. ESPs work best under normal resistivity conditions. Resistivity, which is a characteristic of particles in an electric field, is a measure of a particle's resistance to transferring charge (both accepting and giving up charges. Resistivity is a function of a particle's chemical composition as well as flue gas operating conditions such as temperature and moisture. Particles can have high, moderate (normal), or low resistivity. A better way of displaying this would be to solve for resistivity as a function of applied voltage and current, as

$$\emptyset = AV(IL)^{-1} + b = c \qquad (1)$$

Where, ø = Resistivity in ohm-cm;

V = DC potential in volts;

I = The measured current,in amperes;

L = The ash layer thickness in cm and

A = The current measuring electrode face area (cm^2).

Table 1. Resistivity levels

Resistivity	Measures
Low	between 104 and 107 ohm-cm
Normal	between 107 and 1010 ohm-cm
High	above 1010 ohm-cm

Resistivity is the electrical resistance of a dust sample 1.0 cm2 in cross-sectional area, 1.0 cm thick, and is recorded in units of ohm-cm. The table above, provides standard value ranges for low, normal, and high resistivity. A potential electric field (voltage drop) is formed across the dust layer as negatively charged particles arrive at the dust layer surface and leak their electrical charges to the collection plate. At the metal surface of the electrically grounded collection plate, the voltage is zero. Whereas at the outer surface of the dust layer, where new particles and ions are arriving, the electrostatic voltage caused by the gas ions can be quite high. The strength of this electric field depends on the resistivity and thickness of the dust layer. In high resistivity dust layers, the dust is not sufficiently conductive, so electrical charges have difficulty moving through the dust layer. Consequently, electrical charges accumulate on and beneath the dust layer surface, creating a strong electric field. Voltages can be greater than 10,000 volts. Dust particles with high resistivities are held too strongly to the plate, making them difficult to remove and causing rapping problems. In low resistivity dust layers, the corona current is readily passed to the grounded collection electrode. Therefore, a relatively weak electric field, of several thousand volts, is maintained across the dust layer. Collected dust particles with low resistivity do not adhere strongly enough to the collection plate. They are easily dislodged and become re-entrained in the gas stream. The electrical conductivity of a bulk layer of particles depends on both surface and volume factors. Volume conduction, or the motions of electrical charges through the interiors of particles, depends mainly on the composition and temperature of the particles. In the higher temperature regions, above 500 °F (260 °C), volume conduction controls the conduction mechanism. Volume conduction also involves additional factors, such as compression of the particle layer, particle size and shape, and surface properties.

IV. Factors Affecting Electrical Operation

A. *Production of ions:*

Electrostatic precipitator needs both corona current flow and an electric field for migration of the charged particles for appreciable precipitation of the particulates. It can be observed that there is a relationship between voltage and corona current formation. This relation depends upon radius of curvature and presence of particles in inter-electrode area. There is a point where ionisation of gas molecules begins and production of ions and electrons just start. This is defined as ionisation voltage. With increase in voltage, ions are increased which in turn gives higher corona current.

B. *Spacing of Discharge Electrodes:*

The separation factor of discharge electrodes significantly affects the electric field and the amount of ionisation produced. It is observed that for a tube type precipitators, the number and position of discharge electrode is fixed for optimum operation, where as for plate type ones, the position is within the duct walls for discharge electrodes. Theory says that the optimum discharge electrode spacing is approximately equal to half the duct width. Too close an electrode spacing will result in corona suppression between adjacent element leading to reduced corona flow. For complex controlled emission electrodes, particularly those having protrusions lying parallel to duct walls the above half duct spacing may not be correct since emissions from adjacent points suppress each other. For these type of electrode, optimum element spacing should be obtained either from experimental procedures or by CFD approach.

C. *Collector electrodes:*

Collector electrode should be ‘non-emitting’ with regard to corona emission. This can be achieved by designing large radius of curvature in comparison with discharge electrodes. For maximum performance with the largest collectors, the degree of straightness for tolerance limit is around 10 mm.

D. *Specific Power Usage:*

The efficiency of precipitator depends on amount of corona generated and voltage produced . Particle migration velocity depends is proportional to square of voltage. Collection efficiency can be related to total power consumed. There will be always a small percentage of fine particulate material present in the waste gases. These fine particles typically arise from condensation of initially volatilised feed stock contaminants in the cooler vicinity of the plants. Also, to achieve necessary efficiency, a larger plate area with higher power usage is required. The higher the power that a precipitator will usefully absorbed without arching condition on any field,the higher the efficiency can be achievable.

E. *Sectionalisation of Precipitator:*

It is common to practice to split the precipitator into separate bus sections both in width and length and then to energise each section with its own transformer rectifier unit.

V. Issues and Problems

A. *High resistivity:*

High resistivity can generally be reduced by doing the following by adjusting the temperature; increasing moisture content, adding conditioning agents to the gas stream; increasing the collection surface area; and using hot-side precipitators. Thin dust layers and high-resistivity dust especially favour the formation of back corona craters. Critical back corona with dust layers as thin as 0.1 mm, but a dust layer just over one particle thick can reduce the sparking voltage by 50%. This critical back corona effect on the current-voltage characteristics are: Reduction of the spark over voltage by as much as 50% or more; current jumps or discontinuities caused by the formation of stable back-corona craters; and large increase in maximum corona current, which just below spark over corona gap may be several times the normal current.

B. *Corona characteristics:*

Initiation of corona depends upon free electrons by random sources such as natural radioactivity. Under the influence of an electrical field, these electrons are accelerated to a terminal velocity. The rapidly moving electrons produce additional free electrons y colliding with the orbital electrons of gas molecules and by ionisation. At higher temperatures, flue-gas density is reduced, resulting in a reduced starting potential. Thus, at higher temperatures, lower voltages initiate the corona to start the precipitation process, resulting in more collection for a given voltage than at lower temperatures. Electrostatic precipitators operated at maximum power input have steep corona characteristics; that is, the rate of change of corona current is much greater than the concurrent charge in precipitator-circuit voltage. The steeply rising corona current is further enhanced by increasing temperature of the stack gases. The net effect is to maximize power levels to achieve high efficiency.

C. *Particle resistivity:*

Particulate resistivity is probably the most important basic variable influencing the precipitator and therefore is an important design consideration.A too high level of electrical resistivity or too low level causes collection difficulty. A high resistivity dust, such as sulphur, does not readily give up its negative charge and assumes a positive charge. This causes the particulate to be repelled back into the gas stream of negatively charged particles. A low resistivity dust can be collected and repelled in this manner many times before finally being emitted to the atmosphere. Therefore, the presence of large quantities of carbon in the ash can adversely affect the collection efficiency of a precipitator. One thumb rule followed by designer is to downgrade the efficiency of the unit by 1% for every 1% of carbon in the gas over 15%. Therefore, one always wishes a medium resistivity for good collection efficiency. In coal fired boilers, sulphur in the form of SO_2 affects resistivity. Resistivity has two components, one related to the bulk of the material and another is related to the surface of the particle, absorbed layer of gas. As the temperature increases, the absorbed surface contaminants evaporate and surface resistivity increases. And with all insulating materials, the volume resistivity increases with decreasing temperature.

D. *Rapping Behaviour:*

This is perhaps the most complex among the three performance steps. Non electrical adhesive forces which play a significant role in plate rapping, vary inversely with particle diameter, but depend generally on the chemical and physical nature of the particle. Moisture can increase adhesion at lower temperatures. Particle resistivity has a critical effect on the electrical force causing particles to slick to the collection plates: the more resistive the particle, the greater the force. Operation at low temperatures and high resistivity requires considerably more rapping acceleration on the collection plates than it does under normal resistivity, and higher temperatures. Conventional practice limits maximum average gas velocity in high resistivity and low temperature operation to approximately 1 m/s. This limit avoids losses due to re-entrainment of particles which can occur when the dust layer is dislodged violently. In contrast, precipitators run at 1.7 m/s gas velocity at higher temperature.

E. *Gas Velocity:*

There are two forces acting on a particle having direct right angles to each other. First is due to the flow of gas and second is produced by the electric force on the ionised particle perpendicular to the motion of the gas. The path followed by the particle will take direction which is resultant of the two forces mentioned above. Therefore the efficiency of the collector decreases with an increase in velocity which can be compensated by increasing the voltage supplied to the plates.

F. *Humidity Conditioning:*

The moisture content of the flue gases has an important role in determining the electrical resistivity of the particulates and hence precipitator electrics and performance. Although chemical reagent injection is usually considered the preserve of the power industry, it has been used on other process plants to enhance the performance of the precipitation plant. There are, however, a number of processes where moisture conditioning is essential to minimise the precipitator size to produce a cost effective solution. Usually these processes derive their waste gases without the use of carbonaceous fuels, such as electric smelting or oxygen refining of iron, but there are some such as dry process cement manufacture, particularly when the raw meal mill is not in service, which require moisture conditioning to produce acceptable efficiencies. Generally these processes have specially designed cooling towers preceding the precipitators, where water in injected in fine droplet form to ensure evaporation to avoid carryover problems arising. In addition to reducing the particulate resistivity, moisture injection also decreases the gas volume and temperature of the gases being treated, which reduces the size and hence cost of the precipitator, although a cooling tower will add to both capital and operating costs. As an alternative to chemical conditioning, on some power plants moisture has been injected into the ductwork immediately in front of the precipitators and achieved significant improvements in performance. The difficulty with this approach is that, with an exposure time of less than 1 s and a gas temperature of around 130 °C, the size of the injected water droplet is critical. To minimise the injected droplet size, two fluid atomisers are essential to ensure complete evaporation of the water in order to eliminate fall out and build up problems downstream of the injection point.

VI. CONCLUSION:

From theoretical point of view, it is clear that it is not possible to have a electrostatic precipitator that works at 100 per cent efficiency levels, but with point compromises, the optimal conditions can be achieved. With analysis softwares like ANSYS® and freeware open source like openFOAM® it is possible to achieve optimality. The gas velocity can be iterated to find optimum velocity in analysis softwares, the design- by constructing with respect to flow pattern and appropriate particle resistance ranging from 108Ωcm to 1010 Ωcm.

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