REVIEW OF DESIGN OF ELECTROSTATIC PRECIPITATORS

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Abstract: The study of design of Electrostatic Precipitators (ESP) is conducted to understand the parameters which are responsible to increase or decrease the collecting efficiency of ESPs; after understanding the design of ESP an equation in given for the collecting efficiency for an ESP. Migration Velocity has also been discussed which is a very important aspect to determine the collecting efficiency of an ESP.

Keywords – ESP, Migration velocity, Collecting efficiency

1. INTRODUCTION

In October 1948 a dense cloud of smog was caused due to air pollution in Industrial town of Donora, Pennsylvania. This dense cloud stayed for almost five days, killed 20 people and cause sickness to other 3000 people. In 1952, 3000 people were killed due to London's commonly called "Killer fog". The fog was so dense that buses can't move ahead, not without a guide who would carry lanterns. We all know about the famous foggy conditions in Delhi in which industrial smog plays a vital role. In fact Indian cities are among the most polluted cities in the world; 22 cities from the world top 30 polluted cities are Indian.
Due to the above mentioned incidents the Environmental Protection Agency (EPA) has set National ambient air quality standards for six major pollutants of air which are mostly responsible for major pollution related health issues. These pollutants are Lead, Nitrogen oxides, Carbon monoxide, Sulfur oxides, Particulate matter (PM) and Ground-level Ozone. The standards are periodically revised and may change time to time.
An Electrostatic Precipitator (ESP) is a device which can be used to remove the dust particles or particulate matter from a gas stream or flue gases by the means of induced electrostatic electricity from a high voltage DC supply which makes the ESP as one of the most efficient equipment which helps in reducing air pollution.

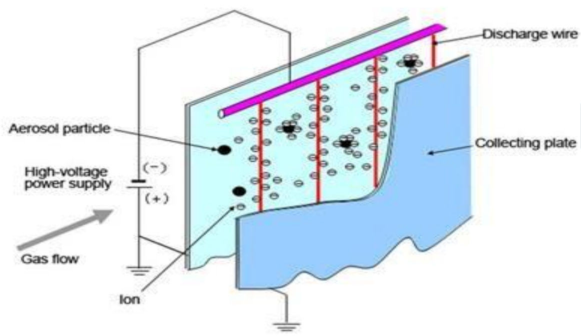

Figure 1: Simplified diagram of ESP

1.1. WORKING PRINCIPLE

An ESP usually has two sets of electrodes which are absolutely isolated from each other and a very high voltage electric field is set up across the two electrodes. One set of the electrodes is called collecting electrodes and the other set is called discharge or emitting electrodes. The discharge electrodes are mostly rigid-frame type or thin wires which are situated exactly at the centre of collecting electrode alignment, the negative polarity of the high voltage DC power supply is given to the discharge electrodes. The collecting electrodes are basically plate type or also it can be of tubular type (mostly in the case of wet ESP), the positive polarity of high voltage DC power supply is given to the collecting electrode and also it is connected to ground.
A very strong electric field sets up in the inter-electrode region which creates corona discharge and thus ionizes the gas molecules and particulate matter as the gas stream flows through the precipitator; the dust particles acquire negative charge and are attracted towards the collecting plate and sticks to it and clean gas flows to the outlet of the ESP. The gathered dust particles are removed from the collecting surface by a process called rapping which can be done mechanically or by means of water.

1.2. TYPES OF ELECTROSTATIC PRECIPITATOR

Based on number of distinguishing features in their design ESPs can be grouped /classified into following:

I. Based on operation of discharge and collecting electrodes and the structural design (tubular or plate).

II. Based on charging method (single stage or two stages).
III. Based on operating temperature (cold side or hot side).
IV. Based on particle removing method from collecting surfaces (wet or dry).

2. INTRODUCTION TO DESIGN

There are two factors which are responsible in determining the efficiency of ESP:

- Size of the unit i.e. aspect ratio or area of collecting surfaces.
- Amount of independent energisation electrically of each particle.

There are various parameters that are required for designing an ESP these are:
Gas flow rate; properties of gas: composition, temperature, pressure; corrosive properties of gas; dust concentration of clean gas; required dust concentration of clean gas; resistivity of dust particles; particle size distribution.

3. MIGRATION VELOCITY

As the charged particle move towards the collecting electrode under the influence of electric field, the velocity of charged particle is called Migration velocity. Migration velocity is a very important aspect and is a function of various other parameters such as: particle size, electric field strength, dust properties, viscosity. Given below is the equation which represents migration velocity.

$$Vpm = qEC/3\pi\mu d$$

Where:
V_{pm} = Particle migration velocity
C = Cunnigham correction factor
q = ne Charge
E = Collector electric field
µ = Viscosity
d = Particle size (µm)

Table 1: Migration velocity of various types of dust

Application	Migration velocity (ft/s)
Sulphuric acid mist	0.19 – 0.25
Blast furnace	0.20 – 0.46
Cement	0.33 – 0.37
Gypsum	0.52 – 0.64
Utility fly ash	0.13 - 0.67

4. COLLECTION EFFICIENCY OF ESP

Deutsch-Anderson gave an equation which can be used under ideal conditions to calculate the collection efficiency of Electrostatic Precipitators. Below shown is the simplest form of the equation:

$$\eta = 1 - e^{-w(A/Q)}$$

Where:
Ƞ = Precipitator collecting efficiency
e = base natural log = 2.718
w = migration velocity of particle, cm/s
A = Effective area of the collecting electrode of ESP, m^2
Q = Gas flow rate, m^3/s

Though this formula is used extensively to find the collection efficiency of ESP at a theoretical level there were some assumptions made before formulating the formula that are not true while practical operation, these assumptions are given below:

- Dust reentrainment has not been considered while formulating the equation.
- Repulsion effect has not been taken into account.
- An assumption has been made that the gas flow rate is uniform throughout the precipitator.
- It has also been assumed that the particle size is uniform throughout the gas stream and also migration velocity is constant throughout the precipitator.
- Particles are charged fully under the influence of electric field.

The more accurate result for the collection efficiency can be achieved by changing or modifying Deutsch-Anderson equation to some extent. This is done by substituting the migration velocity W by average migration velocity W_k; average migration velocity can't be calculated theoretically which is why it has to be done on field. The second modification can be done by decreasing the value of collection efficiency by a certain factor k. This modified equation is called Matts-Ohnfeldt equation and it is given below:

$$\eta = 1 - e^{-Wk(A/Q)k}$$

Where:
η = Collection efficiency
e = Natural logarithmic base
W_k = Average migration velocity, cm/s
k = normally 0.4 to 0.6
A = Effective collection area, m^2
Q = Gas flow rate, m^3/s

5. VARIOUS TERMS RELATED TO ESP DESIGN

I. **Resistivity: -** Resistivity is an electrical property of the material and in this case it is the measure of particle's resistance to transferring charge. Resistivity depends on the chemical composition of the particle as well the operating conditions of flue gas such as temperature and moisture content. It is an extremely important factor that significantly affects the performance of ESP and ultimately collection efficiency.

II. **Electrical Sectionalisation: -** In sectionalisation ESP is divided into various fields along the gas flow, the fields are a series of independently energised bus sections; each field has its own individual T-R set and control circuit. This arrangement provides huge flexibility for energizing various fields at its own condition according to the flue gas operating condition within the ESP.

III. **Specific Collection Area:** - Specific collection area (SCA) is defined as the ratio of effective collecting surface area to the flue gas flow rate through the ESP. SCA represents the A/Q relationship in above given Deutsch-Anderson equation, and from the equation it is very clear that SCA is a very important determinant of collection efficiency. In most cases increase in the value of SCA would call for an increase in collection efficiency.

IV. **Aspect Ratio:** - It is ratio of effective length to the effective height of collecting surface, the effective length means sum of all the length of surface situated in each consecutive field. The aspect ratio must be greater than 1 to achieve collecting efficiency of more than 99%.

V. **Particle Size Distribution:** - Particle size matters a lot for attaining high ESP efficiency. ESPs have lower efficiency for small particles i.e. it is difficult to collect fine particulate, typically less than 2.5 microns. Therefore decreasing the average particulate size will decrease efficiency.

VI. **Corona Power:** - The corona power is the power that energizes separate bus sections and thus creates a strong electric field. The corona power used for precipitation is calculated by multiplying the secondary current of the T-R set by the secondary voltage and is expressed in units of watts.

VII. **Gas Flow Distribution: -** For optimum operation of ESP the gas flow through the shell must be slow and evenly distributed. The gas velocity must be reduced to 0.6 to 2.5 m/s for adequate particle collection, the optimum flue gas velocity is 1.5 to 1.8 m/s. Optimum velocity must be maintained as velocity can't be reduced to a very low value otherwise there will be dropout of dust in the ducts leading to ESP which will affect its performance. Gas diffuser (GD) plates are used to evenly distribute the flue gas throughout the ESP.

6. ESP DESIGN PARAMETERS

Table 2: Ranges of ESP Design Parameters

Parameter	**Range of Values**
Precipitation rate V_P	1 – 10 m/min
Channel Width, D	15 – 40 cm
Specific collection area = Plate area/Gas flow rate	0.25 – 2.1 $m^2/(m^3/min)$
Gas velocity µ	0.6 – 2.5 m/s
Aspect ratio R = Length/Height	0.5 – 2 (Greater than 1 for efficiency more than 99%)
Corona current ratio	50 – 750 $\mu A/m^2$
Corona power ratio	1.75 – 17.5 $W/(m^3/min)$
No of fields	2 – 8
Plate area per field	460 – 7400 m^2

Spacing between sections	0.5 – 2 m
Plate height; Length	8 – 15 m; 1 – 3 m

7. CONCLUSION

A clean environment and a healthy air quality is very important, and an ESP plays a very vital role in maintaining these conditions for us. Apart from just cleaning the flue gases or being an agent of reducing air pollution an ESP can also be very important to increase the total yield of the industry by capturing those particles too which were not meant to be released.

ESPs using catalysts will be very essential in removing fine particulate matter and gas pollutants. Due to health concerns such high performing ESPs will be a life saver in future.

In this paper we studied new way to find the collection efficiency of ESP by using a reduction factor k to make up for reentrainment losses and many other assumptions that were not included in Deutsch-Anderson equation.

Finally we would like to say that ESP is the most efficient way of removing particulate matter from the gas stream and thus it is an excellent equipment to reduce air pollution.

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