Lec 25: Particle Separation by Electrostatic Precipitator

Hello everybody. Welcome to this massive open online course on solid-fluid operations. So as we are talking about the particle separation by different mechanism like that gravity effect based on that cyclonic effect or you can say that cyclone separator or you can say that what is that centrifugal action and there we have learned about that mechanism of gravity effect and centrifugal force how it is acting on the particles and how that particles can be separated based on that centrifugal action compared to the gravity effect. And there we have also learned that what is the collection efficiency of that equipment like cyclone separator and centrifugal separator and also we have learned about that what are the different factors affecting on that collection efficiency. Here also we will learn something more about that particle separation by other mechanism. This mechanism is called electrostatic precipitator.

By this electrostatic precipitator how that particles will be separating based on that force of that electrostatic force. you will see that this type of equipment for separation of that particulate material is generally widely used in industry especially ranging from that cleaning up flue gases from largest power plants to those separation of particles in the household air cleaners like this. So this particulate materials separation based on this electrostatic force is being separated out. You will see that one video how that electrostatic force can be acting on the particles to separate those materials from the dirty gases.

So there you will see that one important components will be coming here that initially that particles will be made charging based on that some charging methodology that is called Corona mechanism that particles first will be charged in the chamber and then after charging that particles whatever charge will be there, there will be also that some electrostatic you or you can say that some electric field will be generated so that that opposite charged particles will be attracted to that electrode in a electric field. So this way that particles will be separated. Here you will see that some that some dirty gaseous stream will be coming to that a chamber where that chamber will be consisting of you will see that some cathode and anode and there that anode initially will be allowed to make it a high voltage effect and around several thousands of voltage to be created there and based on that voltage you will see that either anode or cathode will be discharging some ions to the atmosphere that means in the that surrounding of that electrode or anode. So in that case that ions will be attaching to the particles and after that whenever electric field will be produced that cathode will become accordingly that whether oppositely or negatively charged cathode or anode. So based on that charge of that particles those particles will be attracting to the opposite charged anode or cathode.

So in that case that particles will be depositing on that oppositely charged cathode or anode or it is called electrode. So from that electrode you will see that after deposition of that particles it will be separated either by shaking or other mechanism. So this is basically the principle of that electrostatic precipitator based on which you will see that how particles can be separated just by mechanism of charging of those particles just making that high electric volt in the environment. So let us discuss that things here as per schematic diagram here. So initially you will see that in this picture you will see that incoming gas with particles would be entering to the chamber where you will see that there will be a one that metal plates and also there will be metal rods.

So metal rods and metal plates will be considering as a electrode. Now in that case you will see that that thin metal rods you will see there will be that you will see that one electric field will be imposed on that region through which that charged particles will be flowing. So before flowing that charged particles you have to make the particle charged. So for that you have to use some mechanism to make this particle charged. So that mechanism it is called corona.

Generally at very high voltage you will see that particle will be charged by this corona discharge. What is that corona discharge? Basically when high voltage will be applied between these two electrodes you will see that common electrodes you will see some ions will be released to the air and then air or gas maybe. Gas ions will then to be attached to the particles. So that way particles will be attached by that ions. So whatever type of ions will be produced the particles will become that type of ions.

That means if suppose by corona discharge there will be some electron will be discharge. So negative ion will be produced so that negative ion will be attached on the particles. So particles will become the negative ion particles. And after that an electric field when it will be imposed on the region through which that unique particles will be flowing you will see that that electric field will cause that particle to migrate to the oppositely charged electrode that is metal plates here. And that will be that at the right angles to the direction of the gas flow.

So in this way we can say that initially that after applying that high voltage like several thousands of voltage particles are charged by means of corona which is generally established surrounding a highly charged electrode here as shown in the thin metal rods. So, if you have a gas which is as red one which release electrons at this several thousands voltage environment then an electric field will be imposed on the region through which that the charged particles with gas is flowing. After that the electric field causing the particle to migrate to the oppositely charged particle charged electrode that is metal plates you can see here at the right angles to the direction of the gas flow. So this oppositely charged particles will be depositing on that charged electrode there and those particles will be collected after deposition as a layer on that on the electrode plate and that will be collected periodically by either wrapping it or by other mechanism. So this is the main principle of electrostatic precipitator.

So in very simple way we can say that initially particles will be charged by just corona discharge method and then electric field will be imposed on it and then when particles will be charged it will be migrated to the oppositely charged electrode and there it will be deposited and then it will be collected by wrapping it. This is the simple way to say that how electrostatic precipitator is working. So this is main mechanism based on which you can get the separation of the particles from the atmosphere. Now in this case there are two types of electrostatic precipitator you will observe or you can see in the market. If the same pair of electrodes serves for particle searching and collecting the device is called a single stage electrostatic precipitator.

Whereas there will be two stage electrostatic precipitator they are separate electrode pairs perform the charging and collecting function simultaneously. So these are two stages electrostatic precipitators. So these two types of electrostatic precipitator are available in the market based on the same principle basically that particles will be charged initially then it will be passed to that electric field where that two oppositely charged electrode will be placed and according to the type of charged particles that will be migrated to the oppositely charged electrode and then it will be collected from there. I think you understood that. Now let us see that what is that corona discharge here how does corona form ions here.

We will see that in the picture corona mechanism based on who is that ions is formed. Here in this case you will see that a situation of applied active high voltage at several thousand volts you can say between two electrodes that electrodes may be fine wire or plate or rod that will exploit in generating a corona which forms ions. Here see how corona is formed here. From this electrode you will see that how that corona will be discharging from that electrode and surrounding that electrode the ions will be releasing and then that ions will be attaching to the particles and then those particles as per their characteristics will be migrated to the opposite discharge electrode. So these ions whatever released from that corona at its high voltage from this electrode will charge that particles in the open space.

So this is actually the mechanism of corona discharge based on who is that particle can be charged. Now there should be certain design equation based on which that you can assess this electrostatic precipitator. Here in this picture you will see that one plate where the particles deposited those particles will come from the air stream after getting charged and it will be depositing on its opposite charged electrode. And here the chamber it will have perimeter and some cross sectional area that is denoted by P and AC respectively and through this cross section a gas that will you know flowing containing that charged particles. Now those charged particles will be depositing on the surface of this chamber or this electrode.

Now in this case assume that particle number concentration will be uniform at any point across the device there that means across this that electrode here plate type electrode. Now the electrostatic force on a particle would charge q. Now whenever particles will be charged there will be certain amount of charge will be there that is denoted by q. So this electrostatic force on a particle with charge q can be calculated based on its strength of electric field. So what is that strength of electric field that is denoted by E and charges q. Here the Equation

$$F_{el} = qE$$

So we can say that the electrostatic force on a particle which is acting that will be is equal to Q into E which can be represented by equation number 1. And then when that electrical migration of that particle will happen then particles will be then migrated at a certain velocity that migration velocity can be calculated based on this equation number 2 which is depending on the size of the particle. If you increase the size of the particle that means more finer particles will have more migration velocity that means higher migration velocity whereas coarser particles will relatively have lower migration velocity of that particle. So equation 2 is basically the equation for that calculation of electrical migration velocity of the particle. This is basically Q E Cc by 3 pi mu into dp.

Here the Equation

$$v_e = \frac{qEC_c}{3\pi\mu d_p}$$

This migration velocity also depends on whether these particles are in air medium or liquid medium that you can do also in a liquid medium that in liquid medium particles also can be discharged and then it will be migrated to the opposite discharge electrode. So that migration velocity will be depending on the viscosity of the fluid. Higher viscous fluid will give you that lower migration velocity of that particle. And there will be some other hydrostatic or hydrodynamic behavior whenever particles will be migrating. There may be some collisions between particles and there you will see that particle particle collision may hinder smooth movement of that particles towards the electrode.

There will be hindrance or there will be some resistance to flow of that particles. Because of that uneven distribution of the particles or charge also. So in that case you will see that there will be a some variation of that migration velocity to get that average migration velocity that you have to consider some correction factor. So that correction factor is taken care here denoted by Cc and this is called slip correction factor. Because there will be a collision between particles and because of which there will be hindrance of that migration velocity of that particle and for that you are considering here some correction factor.

That correction factor will give you that value from the experimental observation. Now that is charge q how can you calculate that charge q? The charge q is equal to the product of the number of charges that is denoted by Zp and also the charge on an electron e. So the q will be is equal to generally Zp into e. And then we can assess that what will be the layer thickness that is deposited by that particles or formed by that particle deposition on the electrode. So if we define that wall layer thickness dy such that all particles in dy here in the picture shown in this direction that layer will be there with a particular thickness that thickness can be dy.

So particles whenever it will be depositing with respect to time dy will be increasing and in the axial position suppose that the dx in vertical direction you will see that at a particular x direction for a small thickness of that or small strip of that vertical distance for that what will be the wall thickness that is formed by particle deposition. In that case what will be the fraction of that particles based on that thickness that also you can be able to calculate. So if we consider that if we define that wall layer thickness dy in such a way it is formed that all particles in dy are captured over the distance dx. So we can write dy will be is equal to then Vy into dt because for a small time dt

Here the Equation

$$dy = v_e dt = v_e dx / u$$

if the particles is migrating with VE velocity then you can say that dy will be is equal to ve into dt and then dt can be expressed by dx by u dx is what is that in the vertical direction what is the small distance dx and u is the velocity based on who is that you know gas will be flowing. So you can write dy will be is equal to VE into dt that will be equal to ve into dx by u.

Now based on this you will be able to calculate what will be the fraction of particles that is captured in a distance dx that will be basically the ratio of cross sectional area of the wall layer to the overall cross sectional area of the device. So that will be denoted by this equation number 4 mathematically. So here dx will be is equal to P into dy by Ac.

Here the Equation

$$dx = Pdy / A_c$$

So dx is basically what unit fraction of particles that is captured that will be is equal to P into dy by Ac. Where Pl is the A that will be is equal to collector surface area and u will be is equal to particle laden gas velocity and VE is the electrical migration velocity.

So after that if we do a balance on particle number over the section dx that will give you this equation here. So it is u into Ac into nx minus nx plus dx.

Here the Equation

$$uA_c(N|_x - N|_{x+dx}) = \left[\left(\frac{Pdy}{A_c}\right)N|_x\right]uA_c$$

So this is the difference in number of particles deposition and that will be is equal to what P dy by Ac into nx at this location x into u into Ac. This is basically what the fraction of the particles that is deposited upon what is that cross sectional area that is here. So what will be the cross sectional area and then what is that what will be the volume.

So upon that what will be the total number of particles out of the volume then you can get it. So this number of particles can be obtained from this change of particle number based with respect to time also. So then taking the limit as dx is equal to 0 for a constant time period. So we can say that dy will be is equal to ve into dx by u.

Here the Equation

$$dy = v_e dx / u$$

So in this case integrated subject to n0 is equal to n0 here that is at 0 time.

So n0 will be equal to dn by dx that will be is equal to minus P VE by Ac into u into n.

Here the Equation

$$\frac{dN}{dx} = -\frac{Pv_e}{A_c u} N$$

So equation 5 can be derived from this equation here. So then after substitution of this Ac into u as q we can get this after integration nl is equal to n0 into exponent of minus P Ac by u that integrated 0 to L VE dx that will be equal to n0 exponent of minus A by L by q into integrated within a limit of 0 to L to VE dx.

Here the Equation

$$N(L) = N_0 \exp\left(-\frac{P}{A_c u}\int_0^L v_e dx\right) = N_0 \exp\left(-\frac{A/L}{Q}\int_0^L v_e dx\right)$$

So after simplification and integration you will see that this equation number 5B can be obtained. So this equation will give you that what will be the number of particles within this length L that will be deposited on this particle that means deposited in this electrode within a certain time.

That depends on what will be the initial number of particles already there and also what will be the volumetric flow rate of the particle laden gases and also migration velocity of that particle. So here q is represented here volumetric flow rate of gas through the unit PL is basically the collector surface area and V is the electrical migration velocity and u is the particle laden gas velocity. So from this equation number 5B you will be able to calculate what will be the number of particles deposited within a certain length L. Now after that if the electrical migration velocity can be assumed to be constant so there from this equation number 5B we can have this nl will be equal to n0 into exponent of minus A VE by q.

Here the Equation

$$N(L) = N_0 \exp\left(-Av_e / Q\right)$$

And accordingly the collection efficiency can be expressed by this equation as that eta will be is equal to 1 minus exponent of minus A VE by q.

Here the Equation

$$\eta = 1 - \exp\left(-Av_e / Q\right)$$

$$v_e = \frac{qEC_c}{3\pi\mu d_p}$$

So here that eta will be is equal to what will be the initial minus at a certain time what will be the particle number upon by initial. So based on which you can get this equation number 7 with the help of equation number 6. So that collection efficiency then can be calculated by equation number 7. Where this VE is the main important factor here that will actually affect the efficiency of that collection of particle. Where VE is defined by this equation number 8 here and q also important if you increase the particle laden gas velocity there in this electrostatic precipitator what will happen this exponent of these terms will increase that means here efficiency will be decreased.

So higher gas flow rate will give you that higher gas velocity will give you that and lower efficiency of that collection efficiency. Now some important points that you have to remember in this case of electrostatic precipitator for separation of that particle. So in this case particles are seen in an electrostatic precipitator that will occur in the gaseous space between the electrodes where the gas ions generated by the corona bombard and attached to the particles. And the gas ions may reach concentrations as high as 10 to the power 15 ions per meter cube. Also one important points that a 1 micrometer particle typically acquires the order of 300 electron charges whereas a 10 micrometer particles can attain 30,000 electron charges.

So this is the actually typical some important points that you have to remember here. That means here that electrostatic precipitators efficiency depends on particle size and strength of the electric field and also flow rate of the particle at in gas. And main important point here particle searching for this electrostatic precipitator. And the level of charge that is attained by the particle that depends on gas ion concentration also conductive properties of the particle electric field strength and particle size. So these are the core points that is very important whenever you are going to charge the particles.

Actually that two mechanism by which the particles can be charged. One is called field charging another will be diffusion charging. These two type of charging depends on actually the flow characteristics of the particles. In the field charging you will see that ions are accelerated towards the particles by the external electric field. So diffusion charging it is caused by the irregular thermal motion of the ions.

So that you have to remember there are two types of particle charging, field charging and diffusion charging. Up to this you have to remember at least. The field mechanism dominates for particles which will be larger than 1 micrometer in diameter. Whereas the particles smaller than 0.1 micrometer in diameter will be having that domination of that diffusion mechanism for its searching.

So we understood from this lecture what is the electrostatic precipitator, how that electrostatic precipitator will be working. Similarly the particles are supplied or particles are allowed to pass through that electrostatic precipitator where the electrodes will be there either in one stage or two stage mode where one electrode will be discharging that ions by corona bombarding in an atmosphere of high electric volts and after searching those particles it will be migrating to the opposite discharge electrodes which is actually made based on that imposition of the electric field in the chamber. And when that particles that is opposite discharge depositing on the opposite discharge particles it will be collected by wrapping or other mechanical way and then you have to assess what will be the concentration of that particles or fraction of particles that is deposited out of total volume of that particles to be supplied and based on which this you will be able to calculate what will be the efficiency of the system and what will be the governing equation for calculating that collection efficiency for this electrostatic precipitator that we have discussed here and based on that equation you will be able to calculate. That collection efficiency depends on charge of the particles, volumetric flow rate, even migration velocity and size of the particles. I think you understood this mechanism of this electrostatic mechanism of particle separation.

In the next lecture we will try to discuss more about that separation of particles which will be how that particles can be separated by filtration that is by fabric or other way. So in the next lecture it will be discussed about that separation by industrial fabric or bag filters. So thank you for giving attention. Have a nice day.