Lec 22: Separation of particles by Screening

Hello everybody welcome to this massive open online course on solid-fluid operations. So, today we will start another module that is called the separation of particle materials by different methods. So, in this lecture today we will try to discuss about the separation of particles by screening. There are several other methods which are available to separate the particulate materials whether it is coarser or finer according to that size the particulate materials is being separated by different techniques. And also there are several equipments that are available by which you can segregate or separate those particulate materials either in from the effluent of that industry through some through some duct from the industrial outlet or the particulate materials which are available in open air or atmosphere and also those particles how to separate. Also in laboratory scale sometimes you have to separate the materials based on their size and how to do that you will be knowing about those techniques here in this module.

So today we will discuss about that separation of particles by screening. Here in this lecture what is the screening and what are the standard equipment that is available for the screening and what is the efficiency or effectiveness of the screen or sheave that will be discussed. So, what is the screening? Basically it is a method for the separation of particles according to size. You will see that in industrial screening the solids are dropped on through dropped or thrown against a screening surface.

In this case you will see that some particles will be segregated based on their size just by a mechanical provision where you will see that some opening of that mechanical provisions will be there through which that particles will be coming out just from the mixture based on their size. So, in that case those particles which will be coming down or pass through that opening of that mechanical provision it is called sheave or screen that will be called undersize or fines. And those undersize particles pass through the screen openings and those who will be left on the on the surface of that screen that will be called oversize that means the size of that particles will be higher than the openings. So, that will be left over on the surface of that screen. So, that is called oversize or sometimes it will be regarded as tail somewhere you will see that some particles will be taken out with their you will see that special size or desired size as a tail also.

So, in this case you will see that the undersize even oversize particles will be there after segregation and based on that capacity of undersize or oversize after separation that will be used to analyze the screen efficiency or effectiveness. And single screen that separates that solid mixture into two fractions of this then undersize and oversize particles there. And you will see that from that feed mixture you will get this undersize and oversize particles at a particular fraction of a specific material and those specific material concentration or fractions that will be used to analyze that effectiveness or efficiency of the screen or you can say that separating devices. So, in this case screening generally a special terms that is being used in a laboratory scale operation and that is called screen or sheave you can say that. Here in this slide a picture is shown that here different sizes of screen are shown here.

You will see that this screen actually is categorized based on the number of openings of the screen. Now here if you are having the more number of openings that means there the size of the openings will be small whereas if you are having bigger size opening that means here number of openings will be less. So, accordingly that number of size of openings, number of openings and size of the openings are based on which that screen or sheaves are categorized. There are different sizes of screen or sheaves are available. So based on which you can get the different sizes particles after being operated by this screen.

So, material passed through a series of screen of different sizes is separated into sized fraction. Here you will see that standard screen if you are talking about a standard screen here you will see that the screen will have different meshes. You will see that that will be called as mesh number here 4, 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150 and 200 like this. These are the mesh and this mesh will have certain opening size. So based on that opening size what will be the number of openings that also can be you know obtained.

So in this case if you are having that mesh number 4 in this case the screen opening will be of size 4.699 millimeter. Similarly if you are increasing that mesh number you will see that 4 to suppose 200 in that case this opening size of that mesh will be reduced. So at the higher here up to 200 if you are considering this is the standard screens mesh number or screen size in the laboratory scale. So it will be for 200 mesh where the opening size will be 0.

074 whereas the bigger size screen that means opening size will be higher in that case and mesh number will be lower in that case it will be called as mesh 4. So its opening size is 4.699. In that case accordingly you will see that if you are using these different meshes with those different opening sizes and if you use these different meshes for you know segregating the particles based on their size you will see that if you have suppose certain amount of feed mixture which will be segregated based on their sizes with those mesh then according to that opening size the particles will be segregating okay. That means the opening of that size based on their size the particles will be going downward or pass through as per their opening size.

So here those who are passing through that opening size what will be the mass fraction of that material which will be passing through that opening. So that is actually expressed by Xi and if you consider that cumulative way of that mass fraction that can be calculated in this way. So initially you will see that if you are using that mass fraction of that certain material where you will see that all the particles will be above that opening size of 4.699 that means you will say that no material to be passed through that mesh of mesh number 4 which have the opening size of 4.

699. So in that case the mass fraction will be 0 there whereas if you allow it through that mesh number 6 you will see that the opening size of 3.327 you will see that some amount of

material should pass through whose have the size around 3.327 millimeter and those materials will have the mass fraction of 0.0251. Similarly for other meshes you will see that if you use all the meshes you will see that up to certain mesh number you will see that all the particles will be coming through no particles will be remain on the screen.

So in that case you will see that at the you will see that they are the 200 mesh that the mass fractions will be around 0.0031. So in this case you will see that this mass fraction will be depending on that opening of the screen size and accordingly that you can have a correlation for this like this Xi will be is equal to 0.336 into e to the power minus dpi minus 1.572 whole square divided by 0.621.

Here the Equation

$$x_i = 0.336e^{-\frac{(d_{pi}-1.572)^2}{0.621}}$$

So from this correlation you can easily calculate what will be the mass fraction of that materials after segregation and also you can make a correlation for the screen opening as dpi that will be is equal to depending on that mesh number which will be correlated by this equation. So what will be the screen opening and if you have that mesh number then you will be able to calculate what will be the screen opening size. So in this case you have to remember that the set of screens is based on the opening of the 200 mesh screen which is established at 0.074 millimeter and the area of the opening in any one screen in any one screen is the series in the series you can say is exactly twice that of the openings in the next smaller screen. What does it mean that here what is the area of opening in any one screen any one screen suppose this one this is your opening of this screen so area of this opening of this it will be that if you are considering the square opening it will be generally so 1.

651 into 1.651 that will be your area. So this area in this series is exactly twice that of the opening in the next smaller screening. What is the next smaller screening? So this is this one so if you again find out the area of this smaller screen then it will be coming as 1.168 into 1.168 this will be your area so this area will be almost twice of this area of this opening area so this is like this.

Also one thing you have to remember that ratio of the actual mesh dimension of any screen to that of the next smaller screen will be is equal to root over 2 that will be equal to 1.41 that means here this one this opening will be is equal to 1.41 into this opening. So these are called standard screen and this screen are also called as Taylor standard screen series and the most common modern sheaves are in size such that the ratio of the adjacent sheave sizes is the 4th root of 2. So that is for modern sheaves this is not the standard of that Taylor series here it will be at modern they are defining they are designing this sheaves in different way so they are having this sheaves as like that the ratio of the adjacent sheave size will be 4th root of 2.

So like this here suppose the sheaves are like 45 number, 53 number, 63, 75, 90, 100, 7 millimetre. So in this case this sheave of 53 will be is equal to next one what is that previous one is 45 and next one is 53. So in this way we can say that 53 will be is equal to 42 into 2 to the power 1 by 4. So in this way they are designing that mesh in the modern sheave. Then we are talking about that screening also in industry use.

So in that case the industrial screen are made from woven wire, silk or plastic cloth, metal bars, perforated or slotted metal plates or wires. So in that case different types of screen you will get that maybe base wise or the base operated or continuously it will be operated. So this screen will not be the same as that laboratory scale screen. It will be some other way but main purpose is to segregate those materials in the large capacity. So various metals are used in this case you will see that stainless steel the most common here and in this case the screens are to be shaped or gyrated or vibrated either by mechanically or electrically.

So here you will see that in this picture here animated here you will see that in this case the feed materials will be passing in a pan whereas whenever it will be fed to a vibrating screens there the solid materials will be passing through that opening of that screen in this pan and after vibration you will see that those who are not passing through that openings those will be taken part in different storage whereas that those are coming through that openings those will be taken into another storage tank. So in this way it will be segregated based on that opening of that screen. So here basically that screens are vibrating in that vibration will give you that that is driving force to pass through that opening of that screen. So any screen whatever you are talking about there will be certain opening that opening either in a fashion of that circular or that rectangular or you can say that longitudinal or you can say that it will be square opening or sometimes you will see triangular openings also there. So to operate those things so industrially for continuous operation that you have to give some external forces.

Those external force will vibrate that screen so that that materials which are size of less than openings it will become down through that screen openings. And then we are having you will see that other things here like different types of industrial screens it is called stationary grizzlers. stationary grizzlies they are generally these grizzlies they grid of parallel metal bars set in an inclined stationary frame here as shown in the picture. The slope and the path of the material are usually parallel to the length of the bars here you will see that here in this picture shown. The large chunks roll and slide to the tails discharge small lumps fall through here.

Here you will see that those who are smaller in size compared to these grid gaps those will be coming down through this grids whereas the larger size of this grid openings it will be roll down over the surface of the grids. So in this way this static grizzly screens will separate those materials. So in this case large chunks roll and slide to the tails as a discharge whereas small lumps will fall through the opening of this grizzlies. And in cross section you have to remember that the top of each bar should be wider than the bottom so that the bars can be made fairly deep for strength without being choked by lump which will be passing partly through this grizzlies. And the spacing between the bars will be 2 to 8 inch generally within this range this the spacing of these bars to be maintained whereas it will be actually 50 to 200 millimeter in size.

So that you have to remember. So one important equipment for this particle separation in industrial scale it is called stationary grizzlies. Another it is called the gyratory or vibratory screen. Here in this shown picture it is shown that there are different type of gyratory or vibratory screens. Here in this case the screens are to be externally moved by certain force that may be either by this is called electrically or mechanically shaking or rotating you can say that continuously so that particles will be separated. So two screens are above the other are held in a casing inclined at an angle between 16 and 30 degree with the horizontal you will see that here one gyratory screen as shown here in the picture.

In this case casing and screens are gyrated in a vertical plane about a horizontal axis by an eccentric. The rate of gyration is generally maintained 600 to 1800 rpm and this screens are generally rectangular and fairly long typically 0.

5 to 1.2 meter length to the 1.5 to 4.3 meter breadth like this or 0.5 to 1.

2 meter wide and 1.5 to 4.3 length. So this particle here in this case will fall from the lower ends of the screens into a collecting ducts after separation. So in this way you can have this segregation of this material or separation of the materials based on their size either by static or continuous or gyratory vibratory screen. And then you will have you will see that other type of you will see that the screen it is called centrifugal shifter. In this case the screen is a horizontal cylinder of woven metal or plastic. The high speed helical paddles on a central shaft that will impel the solids against the inside of the stationary screen as shown in the picture.

We will see that and in this case fine pass through that screen whereas over size is conveyed to the discharge port by this equipment. So here it is called centrifugal shifter. So you can see what is that the screen is a horizontal cylinder here as shown in the picture here. And it will be made by woven material or plastic you can say and whenever the high speed helical paddles on the central shaft it will be applied you will see that it will drive that solid materials against the inside of the stationary screen just allowing it through the screen openings. So during that operation the fines will pass through that screen openings and whereas that oversize materials will remain inside that cylinder and it will be taken out through the discharge port.

Now one of the important point that you have to know or you have to remember also whatever basic equipments to be used for segregating this material based on the size by an equipment you have to know what is the effectiveness or efficiency of that equipment. That screen effectiveness or efficiency that will be defined based on that you know measure of the success of the screen that means what degree of separation will be there for a specific material by that equipment. So that efficiency of the screens depends on that size of the material you know as well as you can say that type of materials whether it will be very dried or sticky and also it depends on that interaction of the particles inside that you know equipment. So the screen effectiveness that you have to know what is exactly that and how you can estimate that screen efficiency or effectiveness, okay? So it is basically a measure of the success of the screen in closely separating that material suppose type A and type B which is in a mixture and if the screen functions perfectly then you can say the all the material suppose type A would be in the overflow and all the material B would be in the underflow. That means if a mixture of A and B you are getting then you are going to separate this material A and B by a certain equipment of that screen as a screen.

So screen efficiency will be depending on that if the screen effectiveness will be perfect or 100 percent efficiency it will give you if you are having all the A type particles at in the under size whereas that all the B materials will be in the oversize or under size according to that size, its size. So perfectly operated or efficient screen that will give you the complete separation of that category of the material, okay? So here you will see that let us consider one screen like this as shown here diagram. This is a screen of that equipment through which that particles will be passed through and some particles which are having that bigger sizes of this screen opening will be retained on that screen that will be as overflow whereas the particles which will be coming down through the screen that will be regarded as a underflow and the feed material will be a mixture of overflow and underflow materials. So whenever feed material pass through this screen that screen either operated by mechanically by shaking or electrically by shaking you will see that the materials will be passed through that screen opening those who have the smaller size compared to that screen opening it will be coming downward as a underflow material whereas the bigger size materials compared to that size opening that will be coming out as a overflow. So we can give a name of this suppose feed material is F amount and overflow materials will be coming as a D amount and underflow will be as a B amount.

So we can say that with those concept of this overflowing and underflow materials from this feed material by this screening operation we can do a simple material balance to assess those to assess this screen efficiency or effectiveness. So if we do that simple material balance for materials of say oversize as A and undersize as B you can say that can be done over a screen to calculate the effectiveness or efficiency of the screen. Now if we consider that F is equal to mass of flow rate of the feed, D is the mass of flow rate of overflow and B is the mass flow rate of underflow. Now if we consider that A is the material which is to be separated from the mixture. If we consider that tag or that specific materials let it be A type.

So if we have that mass fraction as Xaf of that material A in the feed and Xad the mass fraction of the material A in the overflow and mass fraction of the material A as Xab in the

underflow streams. Also the remaining fraction that means we can say that 1 minus Xaf, 1 minus Xad, 1 minus Xab that respectively in the feed overflow and underflow will be there. So mass fraction of material B we can say that it will be in that respective feed overflow and underflow. Now if we consider the total balance then we can see that that here feed material that will be is equal to summation of that underflow and overflow or you can write here F will be is equal to D plus B in equation number 1. And if we consider the balance of only material A so in that case in the feed mixture the amount of A will be is equal to F into Xaf and in the underflow the feed material of A will be is equal to B into Xab and in the overflow the D amount then it will be for that A material it will be D into Xad.
Here the Equations

$$F = D + B$$

$$Fx_{A,F} = Dx_{A,D} + Bx_{A,B}$$

$$\frac{D}{F} = \frac{x_{A,F}-x_{A,B}}{x_{A,D}-x_{A,B}}$$

$$\frac{B}{F} = \frac{x_{A,D}-x_{A,F}}{x_{A,D}-x_{A,B}}$$

So we can say that for this material A balance so it will be F Xaf that will be equal to D into Xad plus B into Xab. So this is represented by equation number 2. Now from this equation number 1 and 2 if we eliminate the mass B then we can write D by F will be is equal to Xaf minus Xab divided by Xad minus Xab which is given in equation number 3. Similarly if we eliminate D we can write this equation as B by F that will be is equal to Xad minus Xaf by Xad minus Xab which is given in equation number 4. Now we have to assess that screen effectiveness or efficiency based on that amount of that oversize and undersized material.

Now the effectiveness or screen efficiency either based on material A or B which can be defined as EA or EB. EA is basically the effectiveness or screen efficiency based on material A. So EA will be is equal to amount of oversize material A in the overflow divided by amount of A type material entering with the feed. So those can be defined by this. So what is the amount of oversize material A in the overflow that will be D into Xad and then in the feed that is entering to that screen that will be F into Xaf.

So D Xad by F Xab that will be is equal to screen efficiency based on the material A. Similarly the effectiveness based on the material B it will be based on that amount of undersized material B in the underflow divided by amount of B entering with the feed that will be is equal to B XB B divided by F XBF. So it will be is equal to B from that material balance it will be is equal to B into 1 minus Xab divided by F into 1 minus Xaf. So that will be given that is given in equation number 6. So screen effectiveness or efficiency can be assessed based on that type of material.

So overall effectiveness what will be that? The overall effectiveness can be defined as that E overall that will be EA into EB that means individual effectiveness based on that individual amount of that material A and B then multiplying those or product of this individual efficiency based on that individual material then the overall efficiency can be calculated as EA into EB. So after substitution of EA and EB then we are getting this equation number 7 as D into B into Xad into 1 minus Xad divided by F square Xaf into 1 minus Xaf after substitution and simplifying.

Here the Equations

$$E_A = \frac{\text{Amount of oversize material A in the overflow}}{\text{Amount of A entering with the Feed}} = \frac{Dx_{A,D}}{Fx_{A,F}}$$

$$E_B = \frac{\text{Amount of undersize material B in the underflow}}{\text{Amount of B entering with the Feed}} = \frac{Bx_{B,B}}{Fx_{B,F}} = \frac{B(1-x_{A,B})}{F(1-x_{A,F})}$$

$$E_{overall} = E_A E_B = \frac{DBx_{A,D}(1-x_{A,B})}{F^2 x_{A,F}(1-x_{A,F})}$$

Now if you substitute this value of D by F and B by F in this equation number 7 from the equation number 3 and 4 that earlier we have got in this mass balance equation D by F and B by F if we substitute here in this equation 7 then we can have this overall efficiency of the screen which is given in equation number 8. So in this case it depends on the mass fraction of the particular material let it be A. So in terms of A you can get what will be the mass fraction of that material A in the feed in the underflow in the overflow then you can easily calculate what will be the overall efficiency of the screen.

Now let us do an example with this theory of the screen effectiveness. Here it is said that a material mixture having the screen analysis which is shown in table here and is screened through a standard 10 mesh screen. The cumulative screen analysis of the overflow and underflow are given in table. Calculate the mass ratios of the overflow and underflow of the feed and calculate the overall effectiveness of the screen. So here it is said that the 10 mesh it is being used and also that screening has been done through a standard screen and for various mesh it is done also and accordingly based on that screen opening you can say that the feed materials will be of fraction like this and overflow fractions like this and underflow fractions like this.

Whereas you are talking about that standard screen of the 10 mesh screen here it is indicated that yellow marker here the 10 mesh screen will have that opening as 1.651 and their feed mass fraction is then 0.47 overflow mass fraction of that material A that is 0.85 and that underflow concentration or mass fraction is 0.

195. So if we plot this that particle size that is dp and mass fraction then we will see that this type of profile we can get from the mass fraction change with respect to particle size. So here it will be one profile is for overall another profile is for feed and other one is undersized. You will see that how it will be decreasing fashion with respect to particle

diameter. So since we are talking about that 10 mesh screen so there what will be the you know typical size of that opening that is particle size is 1.

651. So here we are having that 1.651 here in this point and the corresponding value of that undersized fraction is 0.47 here and that overflow is 0.85 here and also you can say that feed is 0.

45 and undersized is 0.195 here like this. Based on this fraction we will be able to calculate then what will be the overflow and underflow of the feed and also effectiveness. Now if we consider that cumulative analysis of this feed of overflow underflow which are plotted here in this picture and accordingly what will be the undersized fraction, feed fraction and overflow fraction as per given condition. So from this table we can say that Xaf we can say here 0.

47, Xad will be is equal to 0.85 and Xab that will be 0.195. So as per that material balance or mass balance you can say the ratio of that overflow to the feed that is from equation number 3 here that we have done here equation number 3 that is D by F. So from this equation number 3 we can have D by F is equal to 0.420 after substitution of these fractions and what will be that ratio of overflow to the feed that will be is equal to B by F that can be obtained from equation number 4 earlier that we have done mass balance. So after substitution of those fractions here then you can get here 0.

58. Now we got this D by F and B by F value and also to calculate that overall effectiveness or efficiency we need to have that fraction of material A in feed underflow and overflow which is given or which are we are getting from this graph at this undersized feed and oversize as here for feed it will be 0.47 that oversize as 0.85 and undersize as 0.195. So to calculate that overall efficiency you can use this equation as we have given earlier after substitution of D by F and B by F here and we are getting this equation number 8 for that overall efficiency.

So after substitution of these fractions in this overall efficiency and calculating finally we are getting this value as 0.669. So your screen is 66.9 percent efficient in your operation to segregate this material of A from this mixture of material A and B.

I think you understood this problem here. Let us do another example here which is given in GATE 2002. There it is said that a sand mixture was screened through a standard 10 mesh screen. The mass fraction of oversize material in feed, overflow and underflow were found to be 0.

38, 0.79 and 0.22 respectively. Now what is the screen effectiveness based on this oversize material? So here it is given that what is the feed mass fraction for this oversize material it is given 0.38. In undersize for that material it is x ID is equal to 0.

79 whereas in oversize so it is undersize 0.22 and oversize is 0.79. And the material balance you can say F will be equal to D plus B and based on that you know oversize material if we do the material balance we can have F into 0.38 into D into 0.79 into B into 0.22 as per that equation of that mass balance equation. So after solving these two equation we can have F is equal to 57, D is equal to 16 and B is equal to 41.

So we are having this what will be the amount of feed, what will be the amount of overflow and what will be the amount of underflow streams. Then you have to find out what will be the screen effectiveness based on the oversize material. So oversize material screen effectiveness can be defined by this here amount of oversize material A in the overflow divided by amount of A entering with the feed that is D x D this divided by F x F. So D we know, F we know x edit is given to you, x F is also given to you. D and F we have found from this material balance which is here and after substitution of those values and calculating will give you that 0.

58. So screen effectiveness based on this oversize material it is coming 58 percent. I think you understood this problem. Then you have to know that what is the capacity of that screen, how that capacity will be related to that effectiveness of the screen. So you have to remember some point here. You will see that the capacity of the screen is measured by the mass of material that can be fed per unit time to a unit area of the screen and this capacity and the effectiveness are basically opposite factors. To obtain maximum effectiveness the capacity must be small and the large capacity can be obtained only at the expense of reduction of its effectiveness.

So very important point. The capacity of a screen is controlled simply by varying the rate of feed to the unit or equipment. The effectiveness that obtained for a given capacity depends on the nature of the screening operation. So these are some important point that you have to remember and also you will see that the effect of mesh size on that capacity screens. The probability of passes of the particle through a screen that is depends on the fraction of the total surface that is represented by openings and the ratio of the diameter of the particle to the width of the opening and the number of contacts between the particle and the screen surface. So these are the points, these are the factors which will affect on the probability of that passes of that specific material through the screen and this actually will affect the capacity of the screen.

Now if you consider a series of screens of different mesh sizes and this practical thumb rules that you have to remember. In this case if you are having that number of openings of the screen area you will see that this number of openings per screen area will be inversely proportional to the square of that some critical size of that screen that is called DPC. So this DPC is basically the size of the largest particle which just pass through the screen is taken equal to the width of the screen opening so that is called DPC. So this number of openings per screen area will be inversely proportional to that square of that DPC and the mass of one particle that will be proportional to that cube of this DPC value and the capacity of that screen that in measured in mass per time it will be proportional to the directly proportional to this size of this screen opening.

So that is called DPC. So the capacity of screen in mass per time divided by mesh size should be constant that you have to remember. Other things that you have to remember capacity of actual screen if you are measure in tons per feet square hour per millimeter of that opening size for normally ranges between 0.

05 and 0.2 for grizzlies and 0.2 to 0.8 for vibrating screens. So these two points also you have to remember. As the particle size reduced the screening becomes progressively more difficult and the capacity and effectiveness are in general low for particle sizes smaller than about 150 mesh. So you have to remember it. So I think you understood that the capacity of the screening different equipment those are being used for segregating the material based on their size. What is the laboratory scale equipment? What is the industrial scale equipment which are being used for that separation of the material based on the size and how to analyze that efficiency of the size from the material balance of overflow, underflow and the feed size material you can easily assess it based on that.

More about this separation of that materials where you will see that very fine particulate materials will be taken care in that case how that separation can be done and what are those suitable equipment for separation of very fine particulate materials which are existing in atmosphere as well as that outlet of that you know industrial effluent and what are the very fine particulate materials of different categories are coming out and how to segregate those materials that will be discussed in the successive lecture. In the next lecture we will try to understand that how particulate material can be separated by gravity chamber and also what will be the mechanism of that separation of those particulate material those are very fine in size. So thank you for giving your attention. Have a nice day.