Lec 2: Characteristics of Single particle

Hi everybody. Welcome to this massive open online course on solid-fluid operations. So in the previous lecture, we have discussed about the brief of different solid-fluid operations. In this lecture, we will try to learn something about characteristics of single particle. Here we will learn: what is the properties of particle, what is the shape of the particle, what is sphericity, what is aspect ratio and also zeta potential? Sometimes the particles whenever mixed with other solid as well as other fluids, It is called a mixture of solids and the slurry. The properties of the mixture of the solids as well as the properties of the slurry will be changing based on the concentration of the particles which is added to the fluid.

So what will be the effective density or effective viscosity of the slurry that also will be considered here. Also zeta potential is basically the measure of the dispersity of the solid particles in a liquid that also to be discussed and how to actually measure that zeta potential that will be discussed in this lecture. So as we know that there are several properties of the particles like shape, size, strength, porosity, zeta potential, particle outline, true density like this. So all those properties of the particles effect on flowability of the particle, reactivity of the particles whenever these particles will be utilized for reaction, then what will be the reactivity of the particles that depends on the size, shape, strength, porosity, zeta potential and also true density of the particle.

Flowability basically whenever particles will be transported from one location to another location you will see that how easy these particles will be flowed based on the size of the particles as well as the shape of the particles. Then this properties also effect on the caking. You will see that sometimes the particles whenever it will be depositing at the bottom of the container or whenever the particles will be separating from the mixture of the liquid and solid that means slurry you will see that they are one membrane medium or you can say that filter medium that we have discussed in the previous class that is being used. So whenever the particles will be separated you will see that on the surface of the filter medium the particles will be depositing and making a layer of the particles. So this layer of the particles is called as cake.

This formation of the cake is called caking. So this caking formation during that separation of the particles depends on its properties like shape, like size, porosity and true density. Then attrition and freeability. It is also one of the important parameter which will be affected by the properties of the particle. So what is that attrition whenever you will see that particles will be interacting with the other particles there may be a chance to make it a finer one because of that high interaction high collision between the particles because of the high energy high kinetic energy in a particular device when it is being used for a particular process.

So at that time you will see that particle-particle interaction will give you the breakage of the particles. So that is called attrition. So this attrition will be depending on the properties of the particle like strength, like what is the size of this particle as well as its shape. Then we are coming to the point adsorption. This adsorption process also affected by the properties of the particle.

You will see smaller size particles will give you the better adsorption because it will have more surface area. So smaller particles will give you more surface area, more surface area will give you the better adsorption. Then coming to the mixing. You will see the uniform particles whenever used to mix you will see that homogeneous mixing will be there whereas different sizes particles whenever it will be mixed then heterogeneous mixing will be there. Any chemical reactions or any other process will be giving the better yield when the homogeneous mixture will be there.

That means almost uniform size of the particles mixture will be there. Then segregation that means you have to separate the particles that also depends on the size of the particles and also density. So if a mixture of that higher density particles with a very lower density particle their segregation will be very easier whereas uniform density particles the segregation will be difficult. So the size of the particles even that both the effects, both the factors will be affecting on this segregation size as well as density. Slurry properties of course if you add more number of particles or more mass of the particles in a liquid in a certain amount of liquid you will see that there will be formation of slurry and their slurry concentration if you increase their density will be increased as well as you will see that viscosity of the slurry will be increased.

Why? You will see that if you add some powder in a liquid and keep on adding the powder of the liquid you will see that gradually increasing the stickiness of the mixture in the container. That means their viscosity will be increased. So if you increase the concentration of the particle in a container their viscosity will be increased. So that is why this slurry properties or slurry viscosity, slurry density will be affected by the properties of the particle. Then coming to that particle shape you will see that there are different types of particles which have different shapes.

So particle shape has a considerable impact upon the performance or processing of particulate materials. What are the shapes of the particles? Generally we see some are acicular you will see that that will be needle shaped or rigid type as shown in the picture here and also some will be angular in shape. You will see that some angular shape particles will have that is will have hard angles as shown in the picture here and also you will see that some particles will be fibrous that means some will be thread like this non-rigid this type of particles. Some will be granular and also blocky that means powder type almost powdered very smaller particles mixture of the small very fine particles will be there. So that will be called as granular that is irregular shaped particles and then mostly you will see that some regular shaped particles that are being used in industry or in a laboratory for performing any processes like spherical particles like cuboid particles, cylindrical, cone or cube shaped particles.

These are called regular shaped particles. So sometimes this regular shaped particles are being used to assess the process in ideally whereas maximum of the process where the particles are being as the catalyst may not be the regular in shape. So in that case irregular shaped particles is being used as a granular material and there will be a certain distribution of the particle size. So within a certain range of the particles that will be considered and what will be the mean for that size distribution that is considered for the assessment. So we are having that different shapes of the particles which will be impacting on the performance or processing of the particulate materials for a particular process.

So these are the different shape of the particles. And then areas in which particle shape have an impact already discussed that the reactivity and solubility, pharmaceutical activities where the particle shape will be affecting. Then powder flow and handling like drug delivery systems there whenever deliver the mixture of the drugs as powder form okay and it will be flowing through the you know vein or channel you will see that there will be a flow resistivity. So that resistivity depending on the particle shape. Then ceramic sinter properties you will see that whenever you will see the ceramic filters will be prepared there of course the ceramic powder whatever it will be used during that sintering process that depends on the size of the particles as well as shape of the particles okay and then texture and feel.

You will see that more finer particles in a food you will see will give you the better texture that means it will be good taste. You will see that fine grinding or fine if you do any food materials which is edible if you make it very crust or fine powder shape you will see that its taste will be different from the coarser size food. So that is why texture and feel will be affected by the shape of the particle. Then how that shape factor can be analyzed or shape can be analyzed. So this shape of the particles can be analyzed by some parameter.

It will be as like aspect ratio, sphericity, roundness, particle outline. So these are the some parameters by which you can assess what extent of this that particle shape whether it is spherical or non-spherical, whether it is that elongated or not elongated okay. How actually round this particle and what will be the roughness of that surface of the particles that can be assessed by these parameters. Like aspect ratio, this is basically the ratio of breadth to length. There will be certain materials what will be the breadth and what will be the length.

If you have the ratio that will be represented by the aspect ratio. Then sphericity, sphericity is the most important parameter by which you can assess the any performance of the process based on this sphericity. It is defined basically we will come to that point how that sphericity will be defined. It is basically how spherical is the particle that is assessed. Then there is also how round is the particle okay that can be estimated by the roundness factor.

And then particle outline, this is also one of the important factor based on which you can assess the performance of the reaction or you can say that assessment of the performance of any processes. In this case, degree of roughness of the surface will be assessed by this particle outline. The size of a particle, you will see that the size of a particle of irregular shape is defined in terms of the size of an equivalent sphere. You will see that in any industry whenever any solid particles is being used for a particular process like that drying, either fluidization or reaction for the catalyst particles, there the particle size will not be regular in shape, will not be always spherical. So to assess that performance, you have to consider that irregular shape particles into a equivalent shape of a sphere.

So in that case, the size of the particle of irregular shape is defined in terms of the size of an equivalent sphere. So irregular shape particles will be considering a regular shape by considering it is an equivalent to the sphere. So particle is represented by a sphere of different size according to the property selected. So there whenever that you are considering the equivalent sphere, either based on that its surface area or either based on that volume of that equivalent sphere or it is the maximum diameter of the equivalent sphere or other way, that will be represented for that equivalent diameter or not, that will be assessed. So how to find out that equivalent sphere or equivalent diameter of that irregular shape particles that will be considered.

Now you will see that important size based on which that equivalent sphere will be considered and based on which you will get the equivalent diameter of the irregular shape particles. So there are several ways. Let us consider that a particle which is irregular in shape here as shown in picture here, particle. Now this particle is see here it is not exactly the spherical in shape. So what you have to do to consider it as a spherical in shape and what will be the equivalent diameter of this particle which is equivalent to a spherical shape.

So there are several way to consider that equivalent diameter, equivalent size of the particle. Here there are several ways shown in the picture. You will see that here if you consider that maximum length of the equivalent sphere, so it is what will be the equivalent sphere and what will be the maximum length, sphere of the same maximum length, it will be considered as the equivalent diameter of that particle. Then you can consider the equivalent diameter based on the sphere of same minimum length like this and you can consider that diameter of this irregular shape particles just by equivalency with the sphere of same volume. You can assess that equivalent diameter based on the sphere of same surface area.

You can have the diameter, equivalent diameter of that particle based on sphere of same weight. You can consider the equivalent diameter of this particle based on considering the sphere that is passing same shape aperture. Shape means what that I think that what is shape that is screen or you can say that chaloni we can say that in Hindi. So there you can say that this is the shape through which that particles will be going down here. So what will be the aperture here? Based on this aperture size that equivalent diameter of this irregular shape to be considered.

And then equivalent sphere of having same sedimentation rate. What will be the rate of sedimentation? That means the same volume or same sphere if you consider that having the you know sedimentation rate or terminal velocity will be the same as that particle terminal velocity. Then what will be the equivalent diameter based on which you have to calculate? So these are the different way by which you can calculate the equivalent diameter of you know irregular shape particles. We will show that different type of equivalent diameter even in a mixer how to calculate the mean diameter of that equivalent sphere or how to calculate the mean diameter of the particles that is exist in a mixer. So that will be discussed in the next lecture itself.

Then we will have here suppose equivalent diameter based on surface area and volume. So there it is a irregular shape particles which has the surface area as Ap. Now if you consider the same surface area of the particle which is spherical in shape. So that means here this area Ap of this irregular shape particles this will be is equal to Ap of equivalent sphere. So if you make equal to this surface area of this irregular and that equivalent sphere then you will be having what will be the diameter of that equivalent sphere that diameter will be considering as the equivalent diameter of this particle which is irregular in shape.

So here surface equivalent diameter it will be called so this is basically dP es is equal to Ap by Pi to the power 1 by 2. Why? How it is coming? Because that Ap will be is equal to what? This Ap is equal to what is that? I think it is Pi dP square. Pi dP square. dP is the equivalent particle diameter. So from which dP e will be is equal to what? Ap by Pi to the power half that means square root of this Ap by Pi.

Here the equation

$$d_{pe,s} = \left(\frac{A_p}{\pi}\right)^{1/2}$$

that equivalent sphere is again equal to this vP then you will see that vP of that equivalent particle it will be 1 by 6 Pi dP equivalent cube. So this vP will be is equal to volume of this irregular shape particles. So if you make it equal then you will get what will be the dP e based on that volume equivalent diameter then you will get that 6 vP by Pi to the power 1 by 3. So here equivalent diameter based on surface area and volume you can easily calculate.

Here the equation

$$d_{pe,v} = \left(\frac{6V_p}{\pi}\right)^{1/3}$$

Now you will see that some other way can be assessed that equivalent diameter of the irregular shape particles. Particles are being used in microscopy. So some diameters used in microscopy based on the projection of the shape of the particle. Here you will see that in this picture it is shown that in this shape here irregular shape particles. Now if you make a circle with area equal to projected area of this particle then you will get what will be the equivalent circle diameter that will be assessed as an or that will be considered as an equivalent diameter of this particle.

Then another diameter it is called ferret's diameter. This is basically that distance between two tangents on opposite sides of the particle. Here see irregular shape particles if you make a tangent at the extreme end of this particle from this side and also from this side and if you make the distance between these two tangents this diameter or length of this between these two tangents what is the distance? This distance will be considered as a ferret's diameter. This ferret's diameter is considered in the microscopy and also you will see that Martin's diameter is also another way to assess the equivalent diameter in microscopy. It is basically the length of the line which bisects the particle image.

Here see that what is the particle image and if you bisect this image if you consider that total length is what from the extreme ends of this particle and then what will the half of this length at this point if you join this line of this end of this particle then the distance will be considered as a Martin's diameter. Another is called shear diameter. This is basically particle width obtained when an image shearing device will be used there. There will be shearing of these two particles and during that shearing point you will see that shearing action and the shearing point if you consider that and at that position at that condition how that particles will be located and then what will be the distance between these two point as shown in the picture that will be considered as a that shear diameter. Another important properties of the particles that is called projected area.

This projected area sometimes considered to assess suppose any flow is getting diverted by the surface of the particles. They are acting a drag on the particles, the pushing of the particles by force. So, they are a streamline of the flow over the particles will be different. So, you will see that that the flow whenever you acting on the surface of the particles to assess that drag force on the particles it will be required to you know what will be the projected area of that particles because that drag force or frictional force that will be considered based on that projected area. So, there are different type of particles with different shapes and if you orient that different shape of the particles in such a way that what will be the projected area that can be calculated.

Here see that cube if you consider from this side of this cube then what will be the projected area. This will be diameter if you consider the diameter the projected area will be D square. So, if you consider a hemisquare particle that projected area will be equal to pi D square by 4. Similarly, for cylinder the projected area will be equal to pi D square by 4 and for cone this projected area will be equal to pi D square by 4 where D is the diameter of that base of the cone. Similarly here if you are considering the cylinder this is laid horizontally okay and if you are considering the projection from the front side what will happen it will be showing as a rectangle as when you are considering as a projected view.

So, that projected view give you the rectangle and what will be that rectangular area that will be considered B into D as per this diagram and it will be considered as the projected area. Similarly, here semi-circular cylinder here hexagon similar to the square that you can consider what will be the projected area. This will be required later on whenever you are going to assess any process there it will be required to calculate what will be the projected area and based on which what will be the surface area to be calculated that is why you need to know this projected area. Then coming to that aspect ratio the ratio of the width to the height of an image of a solid body is called that aspect ratio. So, aspect ratio if you consider this long rod where the diameter of this rod is very small compared to the length of this rod then what should be the aspect ratio this is your diameter by length of this rod whereas length is very very high compared to the diameter.

So, that is why aspect ratio will be equal to what diameter by length or width by length where width or diameter is very less compared to the length that is why aspect ratio is coming almost equals to 0. Whereas if you consider this that almost spherical in particle you will see that here aspect ratio will be is equal to 1 almost because here length and diameter will be same. So, that is why aspect ratio will be is equal to 1. So, always this aspect ratio will be within the range of that here you will see that 0 to 1.

Then another important point it is called sphericity. It is the measure of degree of closeness of the shape of a particle to the perfect spherical particle this is called sphericity you have to know you have to remember this. Why you have to know this sphericity? Because if you are considering the irregular shape particles for assessing the performance of the process or any suppose if you are considering the irregular shape particle then what will be the particles Reynolds number or particle surface area that particle surface area to be considered based on this sphericity. What is the actual surface area and what is the spherical? How what extent of sphere of this or closeness of the shape of the spherical to the perfect spherical particle that will be considered here as a actual that size of the particle. So, sphericity actually whether it is coming to that exactly the perfect spherical or not that will be considered.

So, it is denoted by phi s. So, phi s will be is equal to surface area of a sphere that will have the same volume of the particle divided by surface area of the particle. Now, surface area of the particle as divided by then Ap but as to be calculated from the same volume of the particle. So, after calculating after simplification you will get this one that is it will be pi to the power 1 by 3 into 6 Vp whole to the power 2 by 3 divided by this Ap. Ap is the surface area of the particle, this is surface area of the particle. So, where Vp is the volume of the particle, Ap is the surface area of the particle. Here the equation

$$\Phi_s = \frac{Surface\ area\ \left(A_s\right)\ of\ a\ sphere\ having\ the\ same\ volume\ of\ the\ particle}{Surface\ are\ of\ the\ particle\ \left(A_p\right)}$$

$$= \frac{\pi^{1/3}(6V_p)^{2/3}}{A_p}$$

In this case you have to note it down like if dp is the equivalent diameter of the non-spherical particle and Vp is volume and sp is surface area. Then in another way you can express this sphericity based on this calculation it will come finally that sphericity as 6 Vp by dp into sp. What is Vp? Vp is the volume of the particle, dp is the what is that equivalent diameter of the particle and sp it is the surface area of the particle. So, from which you can get what will be the sphericity. So, you will see sometimes it will be asked what is the sphericity whether it is 6 Vp by dp into sp or dp sp by 6 Vp a different way that will be which one is correct that you have to answer.
Here the equation

$$\Phi_s = \frac{6V_p}{d_p S_p}$$

So, it has actually given in GATE examination 2002 what how that sphericity can be defined. If the dp is the equivalent diameter of a non-spherical particle and Vp is volume and sp is surface area then what will be the definition of the sphericity or how sphericity can be mathematically expressed. So, by this you can easily express. Example let us see that for a spherical particle of diameter d and volume of that particle is pi d cube by 6 then ap will be equal to pi d square.

So, what will be the sphericity? It will be 1. If you substitute the value of Vp ap here in this equation then you will get sphericity will be is equal to 1 for a spherical particle. So, for any spherical particle the sphericity will be is equal to 1. So, you have to remember it. For a cylindrical particle of diameter d let us is equal to 1 millimeter or centimeter or meter or any unit and length is equal to the same as diameter it will be considered as 1. Then Vp will be is equal to what pi dp square l by 4 ap will be is equal to what pi dl into pi d square by 2 ap surface area of the cylinder.

Then what will be the phi s? You have to substitute the value of d that means here l and d both are same this is 1 1 then what will be the Vp you can easily calculate and what will be the ap then you easily calculate after substitution of Vp and ap in this equation again in the definition equation that you can easily have this value of phi s will be equal to 0.873. So, this is the sphericity of a cylindrical particle of diameter and length both are same. Now for a cube of width suppose a any cube of width a then Vp will be is equal to a cube surface area will be is equal to 6 a square then sphericity will be is equal to pi by 6 to the power 1 by 3 as per if you substitute there in the equation earlier for that definition of the sphericity then you will get finally 0.

806. So for a cube of width a the sphericity will be is equal to 0.806. So, let the sphericity phi s of a cuboid whose ratio of length of breadth and height is 1 is to 2 is to 3 that means here length if it is suppose l and its breadth is 2 times of length and height is 3 times of its length then in that case what will be the sphericity. So first of all you have to calculate again what will be the Vp volume of the cuboid. So it will be as like 6l into 2l into 3l and then that what will be the surface area surface area it will become 2 into 2l l into 2l plus 3l into l plus 3l into 2l after substitution of this value of length, breadth and height then you get the sphericity as what is that 0.

47. I think you understood these things that what will be the sphericity of spherical particle that will be 1 what will be the cylindrical particle of diameter and length if it is same then you will get the 0.873 what will be the sphericity of cube of width a that will be equal to 0.806 again what will be the sphericity of a cuboidal shape if its length, breadth and height their ratio it is given or exact amount or exact value of this length, breadth and height is given then you can easily calculate what will be the sphericity. And in this case you have to remember this point that sphericity of the sphere is greater than sphericity of the cylinder is greater than sphericity of a cube. So remember this and as per this calculation we are having this sphericity of sphere is 1, sphericity of cylinder is 0.

873 and sphericity of cube is 0.806. So we can write here 5 sphere is greater than 5 cylinder is greater than 5 cube. So you have to remember this. Now some typical values of sphericity given like pulverized coal whose sphericity will be within the range of 0.

56 to 0.73, crushed coal whose sphericity will be within the range of 0.

63 to 0.75. Similarly activated carbon it is given 0.70 to 0.90. For cement particles the its sphericity is around 0.59, PVC powder its sphericity is 0.81, calcined alumina or hydrated alumina its value is almost 0.

85 or 0.86, fly ash is 0.90, sand 0.86, even crushed sandstone if you consider its sphericity will be ranging from 0.8 to 0.9. Silica gel if you consider what will be the sphericity it will be from 0.

7 to 0.90. Suppose if you are considering the wheat what will be the sphericity of a wheat particle that will be around 0.80. If you are considering that some mica flecks what will be the sphericity of that mica flecks it will be 0.28. Sometimes you will see that Fischer-Tropsch catalyst in the previous lecture we were discussing about that some catalyst is being used for production of different hydrocarbons by Fischer-Tropsch synthesis in a slurry bubble column reactor.

Their catalyst is used. So what will be the size of the particles? There will be certain range this micrometer maybe that 1 to 100 micrometer or 10 to 120 micrometer. Now what will be the sphericity of that particles? The sphericity of that catalyst particles will be around

0.58. Then another important shape of this particle which is to be assessed by particle outline. The outline of a particle can provide that information about properties such as surface roughness okay surface roughness.

How to then assess that things? Here for calculating the particle outline parameters this is basically concept by which you can assess what will be the outline of that particle okay and this concept known as that convex hull perimeter okay. So some convex hull perimeter to be used for assessing that particle outline okay. So for calculating particle outline parameters a concept known as the convex hull perimeter to be used. What is that convex hull perimeter? You will see that any irregular shape particles will have different corners okay. Now if you go if you add this corner by some thread you will see that what will be the length of that thread.

That thread will be considered as a perimeter but that perimeter will be convex hull perimeter. Whereas actual perimeter will be that here as per shown figure actual perimeter will be here shown as red outline. Whereas the convex hull perimeter is considering just by joining this extreme end corners of this particle.

So this will be considered as convex hull perimeter okay. Convex hull perimeter. Whereas actual perimeter is surrounded by at its exact surface okay of the particle okay. So on determining the convex hull perimeter, parameters based on it can be defined such as convexity, solidity or circularity. So the shape can be analyzed based on this convexity, solidity and circularity. We have discussed that sphericity. Sphericity is also one parameter by which you can assess what will be the shape of the particle.

Here the same things it will be coming as per the same concept but here it will be considered as a convex hull perimeter instead of that surface area or volume of the particle. So here the convex hull perimeter is one of the important parameter based on which you have to consider what will be the convexity, what will be the solidity, what will be the circularity. This convexity is defined as convex hull perimeter by actual perimeter. Solidity is the area bound by actual perimeter by area bound by convex hull perimeter and then circularity is equal to actual perimeter by perimeter of an equivalent area circle.

The most commonly used parameter is actually circularity. Let us have an example. What is the convexity, solidity and circularity of a dice of face of length 1 centimeter? Here you say you will see that convexity what is the definition of that convex hull perimeter by actual perimeter. Here since it is the dice of face of length 1 centimeter, this is square shape, dice face is square shape. So here actual perimeter and convex hull perimeter is almost this is same.

So that is why the ratio will be 1. So convexity will be is equal to 1. Whereas solidity which is defined as area bound by actual perimeter divided by area bound by convex hull perimeter. This is also what is the actual area. If its length is 1 centimeter then of course it will be 1 square. Similarly what will be the area bound by the convex hull perimeter of the same.

So it will be also 1. So area bound by actual perimeter divided by area bound by convex hull perimeter it will be 1. Similarly circularity, what is that? This is actual perimeter by perimeter of an equivalent area circle. This is important. Actual perimeter we know that this is 4 centimeter since it is the square surface. And then you have to consider what will be the equivalent area of the circle compared to this square surface area.

So perimeter open equivalent area circle that you have to calculate. What is the area? This is area is what is what is the area equivalent diameter of the projection area of the circle. What is that? The equivalent area of the projection area of the circle it will be root over 16 pi. Here actual perimeter is equal to 4 centimeter. So what will be the actual perimeter? What will be the surface area here? What will be the surface area? This will be 16 pi.

Then what will be the equivalent diameter? It will be root over of 16 pi. So here it will become circularity then 4 by root over 16 pi. So it will be 1 by root over pi. It is coming 0.564. So see here for a dice of face of length 1 centimeter the convexity, what is the solidity, what is the circularity.

Another important point here size of typical powder products. You will see that in a powder in a mixture of particles, there will be a certain range of the particle size will be there in the particles. There may be from the micrometer to nanometer range. So here you will see that some toners, powders, materials their size will be within a certain range here 1 to 10 micrometer. Some example like electronic material, photographic emulsions, magnetic and other pigments whose size will be within a range of 10 to the power minus 1 to that 1 micrometer. And then fumed silica, metal catalyst, carbon blacks, organic pigments, the size range will be 10 to the power minus 2, 10 to the power minus 1 micrometer.

Similarly here, piloted products, industrial chemicals, crystalline materials whose size range will be 10 to the power 4 to 10 to the power 5 micrometer. Granular fertilizers, herbicides, fungicides within a range of 10 to the power 3 to 10 to the power 4 micrometer. So here detergents also I think use, so these are granulated materials. So that will be a size within a range of 100 to 1000 micrometer. Similarly you will see that powdered chemicals like powdered sugars, flour like there, their size will be within a 10 to 100 micrometer.

So you are getting the different powders, we will be also discussing about this powder later on that mixture, how to calculate the mean diameter of this particle though it will have the mixture of different sizes particles. Then another classification of the powder, powder actually the powder that will be classified based on the particle size and also what will be the relative density of that particles compared to the fluid or in a liquid mixture or gaseous mixture. So there are here powders classification as per that Gelders, these particles can be classified into 4 types like C, A, here it will be B, C, A, B, D, C, A, B, D. So C means here cohesive type particles whose size range will be okay within this range and then A type here it will be within this range and then B type which will be within range and D type more than 2000s micrometer in diameter.

Whereas you will see that there density difference will be this. So anywhere if you consider if suppose any powder particle size come within this certain range then you can assess what will be the density difference of that particle and what will be the particle size. So accordingly you can say whether it is A type, B type or C type or D type. C type means cohesive type that means here very fine particles are there intermolecular attraction will be very high that is why the particles will be clogging to each other, agglomerate to each other. So that is why it is called C type particles that means here cohesive type particles. Then A type particles it is aerated that means this particles size range in such a way that it will be easily aerated through the gap of this particles air can be passed easily.

And then that B type particles it is bubbling type particles that means if you use this particles for fluidization you will see that the bubbles will form that is why this type of particles is called the bubbling type particles. And then for drying or some polyethylene production the particle size to be used as a D type particle whose size range will be that more than 200 micrometer. So here A type that means irritable like FCC catalyst, B type bubbles like 500 micrometer like sand, C cohesive like flour, fly ash, D spoutable like wheat, 2000 micrometer arranges. Another type of powder classification is called according to research and Brown 1970, 5 categories of powders are there. Some will be ultra fine powder, some will be super fine powder and some will be you know that granular powder and some will be broken solid.

So here it is given 0.1 to 1 micrometer range that will be called as ultra fine powder. If the powder particles within 1 to 10 micrometer it will be called a super fine powder and if it is size range is 10 to 100 micrometer it will be called as granular powder and its size is 0.1 to 3 millimeter then it will be called as granular solid. Whereas 3 to 10 millimeter size it will be called as broken solid. So as per research and Brown this classification of the powder given.

So you have to know these things what are the different types of powder as per the particle size. Then coming to that Jetta potential. It is actually the measure of the magnitude of the electrostatic or surge repulsion or attraction between particles in a liquid suspension. Suppose two particles suspended in a liquid suspension okay and they are interacting to each other. They may have some charge.

If they are opposite charge then you will see that that will be attracting to each other. If the same ion or same charge then they will be repulsing from each other. So because of that the particles will be dispersing to come to each other or diverge to each other okay or away from each other because of that charge and that dispersive can be assessed by this Jetta potential okay. So it is one of the key parameters known to affect dispersion stability. It can be applied to improve the formulation of dispersions, emulsions and suspensions. How that Jetta potential to be defined? How to calculate that Jetta potential? The Jetta potential can be estimated by Smolosovskis equation.

You have to remember this. Here Xi is equal to mu E eta by epsilon into epsilon 0. What is this epsilon? Epsilon is called Jetta potential. Mu E is basically what is that?

Here the equation (s)

$$\zeta = \frac{\mu_e \eta}{\varepsilon \varepsilon_0}$$

$$\mu_e = \frac{v}{V/L}$$

electrophoretic mobility that means if suppose two electrodes are keep in a solution and then particles with a certain charge you will see that there will be mobility of the particle either to the positive or negative electrode. So the electrophoretic mobility will be there of that particle. Then eta, eta is the dynamic viscosity of that solution and then epsilon is basically the dielectric constant of the dispersion medium. Epsilon 0 is the permittivity of the free space and another point is mu E that is mobility that will be expressed by that depends on actually speed of the particle and also voltage.

What is the voltage applied in the solution by that positive and negative electrode? There what will be the potential difference and also what is the distance between the electrodes. So this mobility, electrophoretic mobility depends on that speed of the particles, even voltage and the distance of the electrode as shown in the picture here. So mu E will be is equal to what? That V small here V is basically the velocity or speed of the particle and capital V is the voltage and here capital L is basically the distance of electrode. So from which you can easily calculate what will be the zeta potential. Now after getting the value of zeta potential, let us see what is happening, how can then we actually assess, what is the stability of that solution or suspension.

So in this case, the absolute value of the zeta potential is larger, many colloidal particles show good dispersibility as the electrostatic repulsion becomes stronger. However, as the zeta potential registers close to 0, the particles become unstable and are likely to aggregate. So the stability behaviour of the colloidal suspension based on the zeta potential can be assessed based on this range. If your zeta potential range will be within to 0 to plus minus 5 in milli voltage, then you can say that the particles will be agglomerated or coagulated to each other in the suspension. If your zeta potential will be within a range of plus minus 10 to plus minus 30 milli volt, then it will be called as incipient instability.

Incipient stability will be assessed by that zeta potential value within the plus minus 30 to plus minus 40 and excellent stability will be having if your zeta potential value coming greater than plus minus 61, then you can say that there will be excellent stability of the particles in the suspension. Another important parameter which is to be known for assessing any performance of the process, they are sometimes used that slurry to be transported from one position to another position. Slurry may be used for the reaction with the gaseous medium. So there you need to know what will be the density of the slurry, you need to know what will be the viscosity of the slurry, effective viscosity of the slurry.

So for that how to calculate the slurry density and slurry concentration and also viscosity that you have to know. So slurry is the mixture of solid and liquid. The density of a slurry can be calculated as like this here, the formula is given. The rho m, what is the density of that mixture that means solid and liquid. This is 100 divided by Cw by rho s plus 100 minus Cw by rho l. What is Cw? Cw is basically concentration of the slurry by weight in the slurry that means what is the weight percentage of the particles in the slurry.

So rho s is the solid density and rho l is the density of the liquid in which that slurry is made. So Cw that means slurry concentration can be calculated by the ratio of weight of the dry solid upon that total weight of the dry solid as well as liquid. So here as per this equation you can calculate what will be the slurry concentration. Let us do an example. It is said that a slurry consists of raw magnetite in a carboxymethyl cellulose solution of density 1600 kg per meter cube.

And from the measurement it was observed that the slurry weights is 2537 kg per meter cube. Now calculate the concentration of solids by weight. Here the density of the magnetite is given as 7874 kg per meter cube. Now the mixture density is expressed as by this equation 100 by Cw by rho s plus 100 minus Cw by rho l. Now this rho m that means mixture density it is given slurry weights is 2537 kg per meter cube.

So it is there but Cw is not given to you which is to be calculated. So Cw is unknown here whereas rho s is known to you, rho l is known to you. So rho s is given as 7874 and rho l is given 1600 kg per meter cube. So after substitution of this rho s, rho l and rho m from this equation and solving you will get this Cw that means concentration of the slurry.

So it is coming as 46.35 percent. Then slurry viscosity. So you will see whenever you add some particles on the liquid you will see that it is you know viscosity. Your stickiness will be the particles that means slurry stickiness will be increasing because of that increasing viscosity. Now what will be that viscosity? How to calculate that viscosity? If you have some concentration of the particles or add some particles or some amount of particles will be added into the liquid. So in that case if you have the extremely low concentrations of fine particles, if your value is less than phi is equal to 0.1 that means 10 percent, less than 10 percent you can say and low shear stress that means 1 kilo Pascal then as per Einstein's equation you can calculate this slurry viscosity as mu l into 1 plus 2.

5 into epsilon s. In case of higher concentration phi is equal to 0.1 that means more than 10 percent and low shear stress that means 1 kPa less than 1 kPa then given by Thomas that

slurry you know viscosity can be calculated by this equation which is a function of slurry concentration. In case of high shear stress and high concentration Kitano et al 1981 they have given another equation they have suggested another equation to calculate the effective viscosity of the polymer smelt of smooth spherical particles. This is equal to phi s will be equal to mu l into 1 minus epsilon s by 0.68 to the power minus 2. Whereas epsilon is volume fraction of the solid in the slurry and mu l is the viscosity of the pure liquid in which you are making the slurry.

Let us do an example here an experimental results the density of a slurry is 1620 kg per meter cube. The density of particle of slurry is 2080 kg per meter cube and that of liquid in which the slurry is made is 1281 kg per meter cube. The viscosity of the liquid is given at 20 degree Celsius as 0.001 Pascal second. Now you have to calculate what will be the concentration of the solid by volume and the viscosity of the slurry.

So concentration you have to calculate as well as viscosity. So first of all you have to calculate what will be the concentration. So concentration can be calculated by this equation that earlier we have calculated from this equation.

So here also Cw is coming 54.63 percentage. Now assume 100 kg slurry is there then weight of solid in it will be 54.63 kg as per this. Now so volume fraction will be epsilon s which is equal to epsilon s is equal to what is that you have to convert it to that volume fraction. So 54.63 divided by 2080 you are actually dividing by what is that 2080 is what it is basically the particle density of the particle in the slurry this is 2080 and then divided by 100 divided by 1620. So this will be your that slurry volume total slurry volume and this will be your what is that particle volume.

So you are getting here 0.425. So here it is seen that its value is more than 10 percent. So we can easily use this equation where the phi s value is more than 10 percent. So here we can use this equation to calculate the slurry viscosity. So after substitution of value of epsilon s and mu L okay then you can easily have this value of viscosity of the slurry as 0.

00388 Pascal second. So in this way you can easily calculate. I think you understood this example. Once this equation okay you try to remember this equation at least Einstein equation you can easily remember okay. So based on which you can easily calculate what will be the effective density. So I think you understood what is the properties of the particle, what is the shape of the particles and what is the zeta potential and how to calculate the slurry density and slurry viscosity and slurry concentration okay. Please go through this lecture notes once again and try to understand if you have any doubt you can directly mail to me I can clarify it okay. So in the next lecture we will discuss about particle size and its distribution also we will discuss the mean particle size in a mixer okay and its distribution. So thank you. Have a nice day. Thank you.