Fluidization Engineering

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Lecture – 03
Particle/Powder Classifications

Welcome to massive open online course on Fluidization Engineering. Today the lecture is on particular powder classification.

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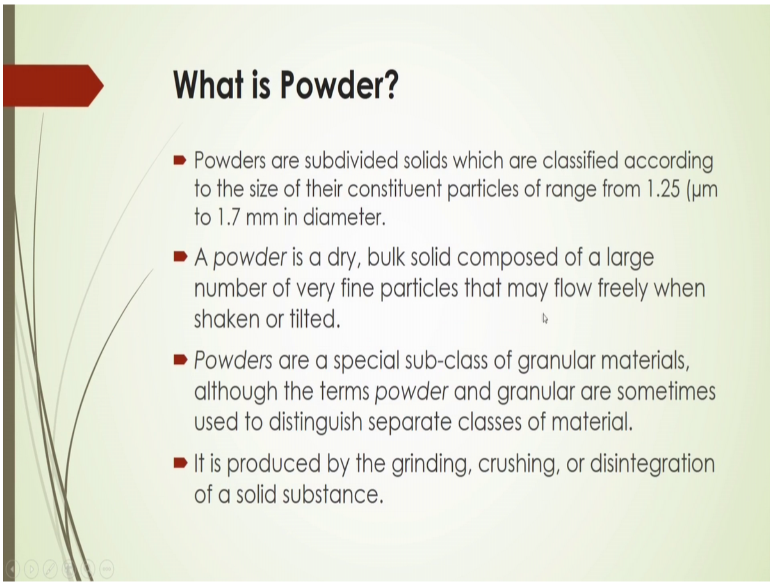

What is powder? The powders are subdivided solids which are classified according to the size of their constituent particles of you ranges from 1.25 micrometer to 1.7 millimeter in diameter. A powder is a dry and these are special subclass of granular materials, although the terms powders are sometimes used to distinguish separate classes of material and it is produced by grinding, crashing or disintegration of a solid substances.

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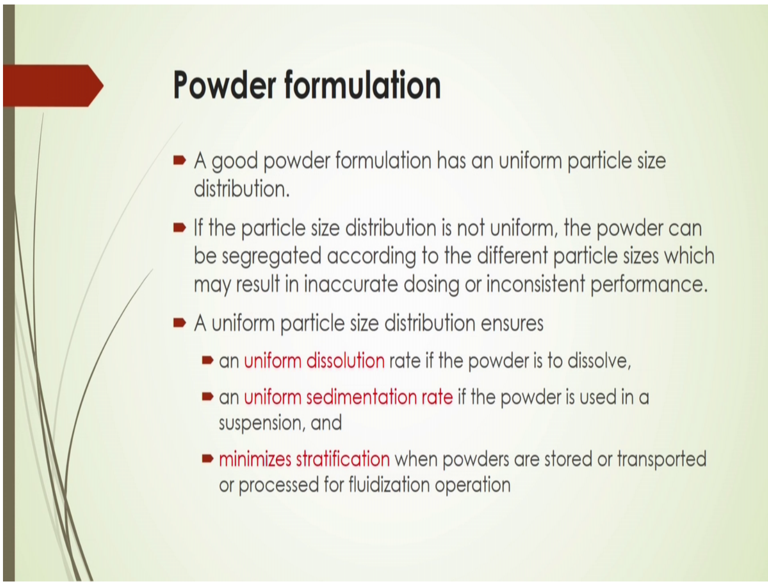

Of course, the powder formulation is the main important task before going to the fluidization operation. Now, a good powder formulation of course, depends on the how the particle size are distributed whether it is uniformly or not that is very important to know. And if the particle size distribution is not uniform the powder can be segregated according to the different particle sizes which may result in inaccurate dosing or you can say inconsistent performance. If the particle size distribution is uniform that is all the particle size in the powder sample are same then you can say it will be a good powder.

Now, uniform particle size distribution ensures an uniform dissolution rate if the powder is to dissolve and of course, it ensures an uniform sedimentation rate if the powder is used in a suspension and it minimizes the stratification when powders are stored or transported or processed for fluidization operation. Now, the reducing the size of the particles in the powder is important job because the reduction of this particle size will give you more uniform size distribution in the sample of powder.

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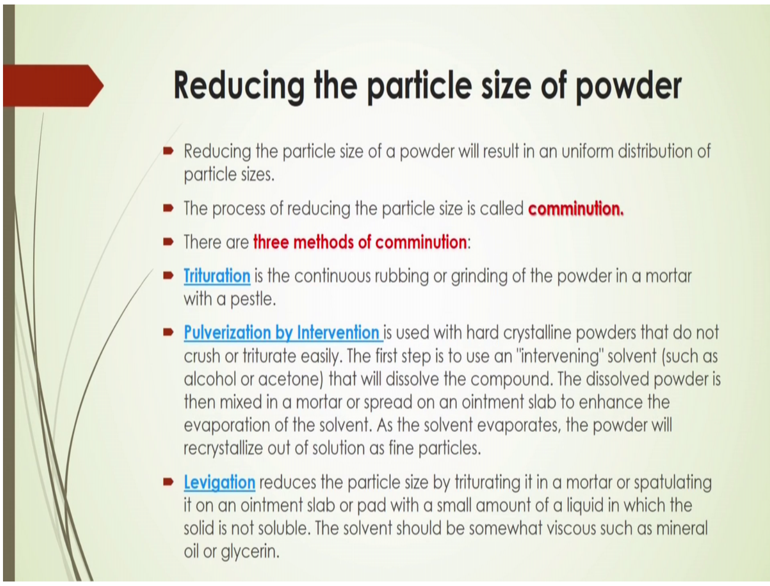

The process of producing of the particle size is called comminution. These comminution is of 3 types generally trituration, pulverization by intervention and the lavigation.

Now, these 3 processes are being used to reduce the particle size for processing of this fluidization operation for different chemical and biochemical industries because the chemical process even in biochemical processes generally in pharmaceutical products of course, the making of powders in fluidization operation the depends on the size of the particles. And how uniformly the size would be made by reducing this particle size depends on its performance or to make the powder formation even the tablet formation in the fluidization operation. Even sometimes the tablet coating that has been done in the fluidization on fluidized bed depends on the size of the particles. More finer particles if you are making in a powder sample of course, there will be the more surface area and more uniform size will be formed even after coating.

Now, what is then trituration method by which you can see the bubbles sorry, this powders particle will be reduced? Now, this is the continuous rubbing or grinding of the powder in a mortar with a pestle. So, this is basically a grinding process and pulverization by intervention is used with hard crystal and powders that do not crash or triturate easily. So, those who are not crush or triturate easily; that means, the crystal and powders that you have to make the size by polymerization or intervention a suitable.

The first step is to use an intervening solvent for this pulverization. The solvent which are being used generally are alcohol or acetone and these step of course, this intervening step will dissolve the compound of this solvent and the dissolve powder is then mixed in a mortar or spread on an ointment slab to enhance the evaporation of the solvent.

As the solvent evaporates the powder will recrystallize out of solution as fine particles. Now, levigation is another one important methods by which you can reduce the size of the particles in the powder. Now, it is the process by which it reduce the particle size by triturating it in a mortar or spatulating it on an ointment slab or pad with a small amount of a liquid in which the solid is not soluble; that means, that means, those who are non soluble solid those soluble, non-soluble solid can be actually done by levigation process to make it finer.

The solvent should be of course, somewhat dispersed such as mineral oil or glycerin to make these particle size lower. Now, the sizing of the particles can be done also by screening initially. So, after screening you will see different classified particles will be forming. That classification can be defined in different way sometimes the particles would be called as very coarse sometimes it will be called as coarse and some are moderately coarse some are fine and some are very fine.

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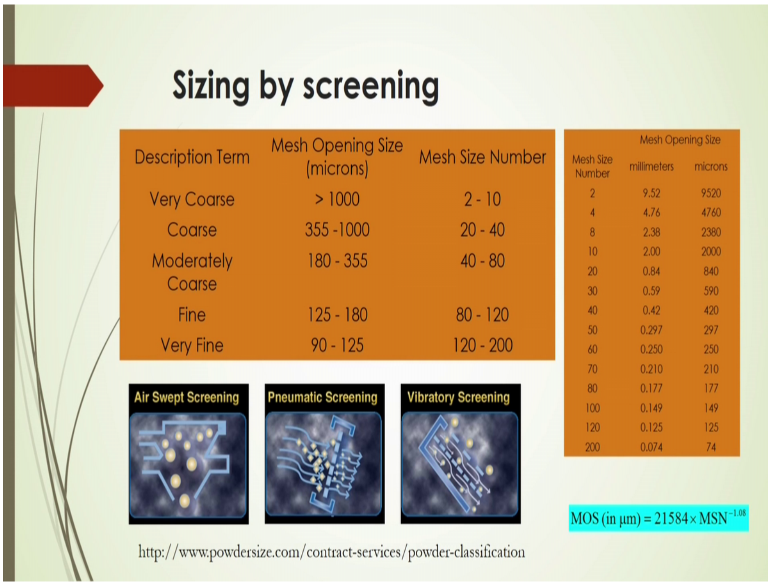

Now, very coarse particles are being generally defined when the particle size is greater than 1000s micrometer and this is being obtained by screening when the mesh size number of the screen is controlled 2 to 10. And coarse sized particles are obtained or is defined when its size is within the ranges of 355 to 1000 micrometer and this can be obtained the mesh size number of 20 to 40. And moderately coarser particles are being defined when the particle size is in 180 to 355 micrometers and this is obtained by 40 to 80 mesh. And fine particles which are being defined as 125 to 180 are obtained by screening by 80 to 120 mesh size number. And of course, very fine numbers particles which are defined if the particle size is less than 125 micrometer, generally 90 to 125 micrometers particles are being defined as very fine particles and this is obtained by the mesh size number of 120 to 200.

So, if you increase the number of mesh size you will see the number of; that means, size of the particles will reduce. So, here in this case you will see in this case here one see table is given that mesh size number in the slides mesh size number corresponding to this what is that millimeter in size of the mesh opening size. So, mesh opening size depends on these mesh size number. And there is a correlations is being obtained here by MOS will be equals to 21584 into msn to the power minus 1.08. That means, here MOS; that means, mesh opening a size is inversely related to the mesh size number and mesh size number is here that like 2 to 200 generally the standard size whereas, mesh opening size within the range of this 9.52 to 0.074 millimeter in a range whereas, in 9520 microns to 74 microns. So, this is the correlation say MOS can be obtained directly if you know the mesh size number as by this correlation.

And this screening methods there are 3 types of screening generally that is air swept screening, when pneumatic screening and vibrating screenings are there.

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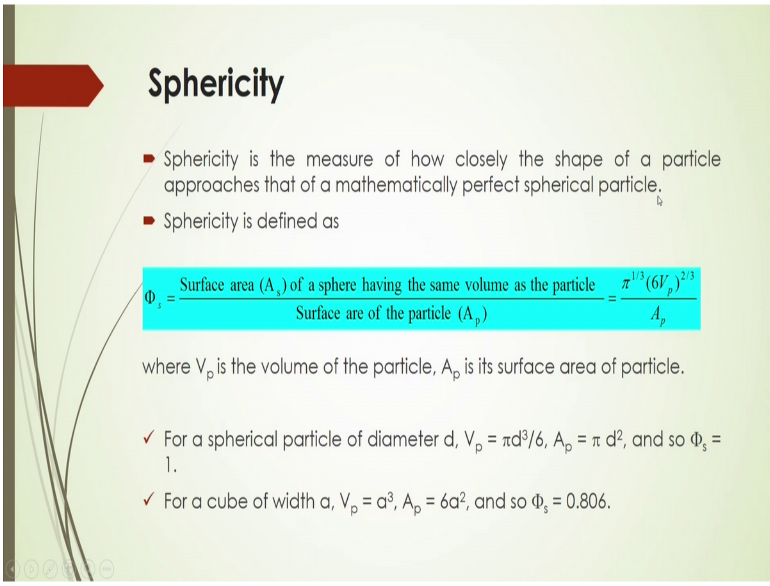

Now, of course, the size of particles in the powder whatever you are getting that powder may not be the same, all the particles may not be same in size, sometimes some particles would be within a certain range some other particles will be within other ranges. So, there are different sizes of particles would be there, but is particles may not be the same in shape also. Same in shape sometimes some particles will be in circular sometimes particles will be in cubical, some particles may be in the shape of needle like sometimes some particles would be within the shape of a like sphericity you can some crystalline.

There are various shapes of particles will be there and some spherical also of course, will be there. But you have to know that what should be the actually equivalent size of that particles if you are having different shape of particle in the sample. Now, you have to consider that equivalent size. So, to get the equivalent size some parameter of course, you have to know by which you can say that how much non spherical it will be and it will be converted to the spherical one.

Now, this sphericity is one measure by which you can say how these particles would be very closely related to the shape of a particle of a perfect to spherical one. Now, spherical is defined as sphericity is defined as that the ratio of surface area of a sphere that having the same volume as the particle by the surface area of the particle. And here this the equation is given that sphericity is denoted by pi s, it is pi to the power 1 by 3 into 6 V p to the power 2 by 3 divided by A p whereas, this V p is called the volume of the particle A p is called the area of the particle, surface area of the particle.

Now, for a spherical particle of diameter suppose d then V p will be is equal to that is volume of the sphere will be is equal to 1 by 6 pi d cube whereas, A p that is surface area will be equals to pi d square. So, if you divide these volume by surface area as per these equation given here in the equation pi is equals to these then you will get that pi s will be equals to 1. So, for spherical particle the sphericity will be equals to 1. Whereas, for non spherical particle suppose the cube of width is a, now what should be the volume of that q it will be equals to a cube whereas, surface area of the cube will be equals to 6 a square.

So, if you substitute this V p and A p in this equation then you will get the sphericity of that cube will be equals to 0.806, even some other non spherical particles also you will get in this way the different is sphericity. So, before going to the fluidization operation you have to consider the particle size as an equivalent particle size by multiplying the sphericity with the original or actual particle size.

Now, how to analyze this particle size in the powder? There are different methods or by different equipments are commercially available by which you can also you can analyze with the particle size.

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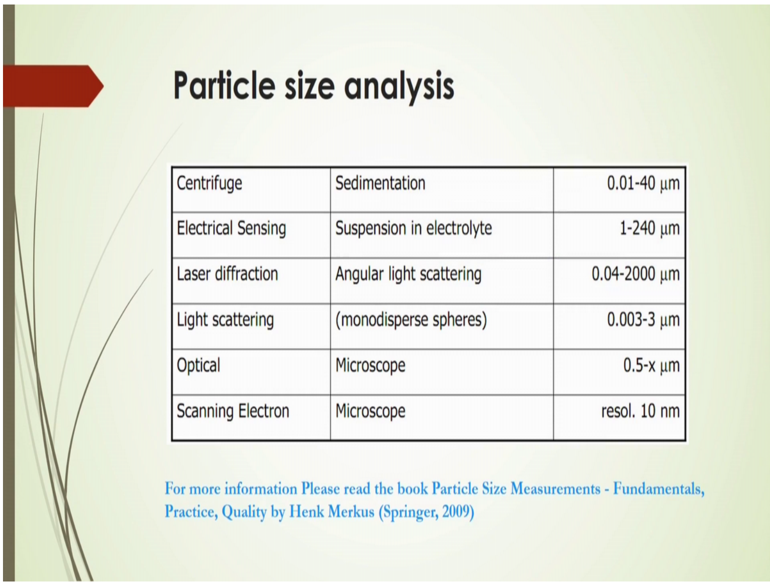

Centrifuge	Sedimentation	0.01-40 µm
Electrical Sensing	Suspension in electrolyte	1-240 µm
Laser diffraction	Angular light scattering	0.04-2000 µm
Light scattering	(monodisperse spheres)	0.003-3 µm
Optical	Microscope	0.5-x µm
Scanning Electron	Microscope	resol. 10 nm

Now, there are several methods like sent tributes electrical sensing even lesser a diffraction method, even light scattering method, even scanning electron microscopic method there are various other methods also available by which you can analyze the size of the particles directly in the by the equipment also and the equipment is being actually designed based on this concept.

Now, sedimentation is one principle by which that centrifuge action, centrifuge by centrifugal action that you can analyze how much actually size will be there. Even electrical sensing method of course, it will sense that what will be the characteristics length of the particles and by which you will be able to get this size. Even this depends on the, that is electrolytic behavior in the suspension. And also laser diffraction that depends on the how much light is scattering that is angular or some other way that by which you can obtain the particle size and optical microscope of course, this is magnifying the server side and then analyzed by the software and scanning electron microscope also is there directly image analysis software will be there by use the taking the image and magnifying and then analysis by which you can get the particle size.

Now, different methods of course, they have some ranges of that is particle size that can obtain. Now, centrifuge that is by sedimentation method you can obtain the particle size within the range of 0.01 to 40 micrometer whereas, electrical sensing that you are getting that will be that you are getting the particle size within the range of 1 to 240 micrometer. Laser diffraction will be within the range of 0.04 to 2000 micrometer. For a light scattering that is generally it is being mono dispersed the spheres in that case almost the size will be very low that is 0.003 to 3 micrometer.

So, whereas, optical microscope it will be magnifying 2 x that is 0.52 micrometer 2 x micrometer that is based on the design of the microscopic operation. And then scanning electron microscope will give the here the size based on the resolution of the picture. Now, it will be depending on the resolution and then 10 micro meter nanometer resolution that whatever the principle you can get it. And more details of this method you can get it from the book like particle size measurements and fundamentals practice quality by Henk Merkus that is Springer 2009, they published very nice books for that you can go further for more information.

Now, powder, you have to classify this powder in different way based on the size of the particles. 1970 according to Richards and Brown, five general categories of the powders are being obtained or they have actually a reported the five categories of the powder based on the size of the particles.

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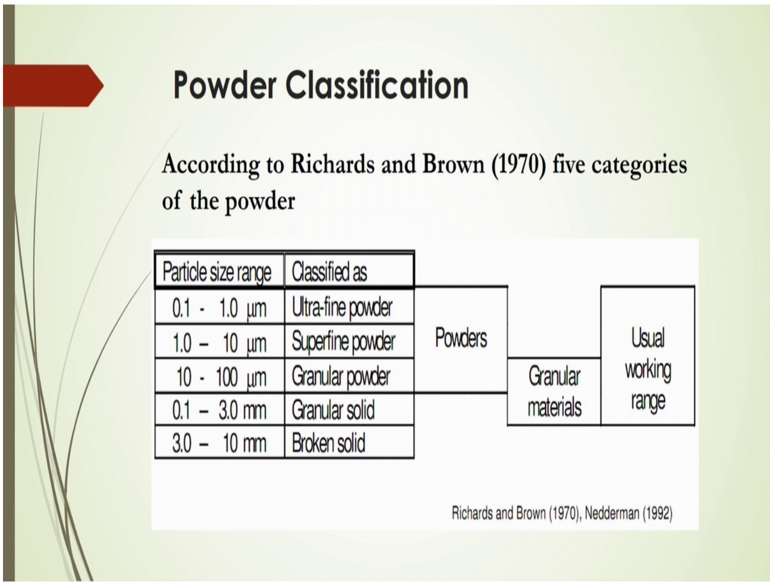

Now, they have classified this powder like ultrafine powder, a superfine powder, granular powder, even a granular solid and then broken solid, based on the size range of the particles. And they have defined this ultrafine powder as when the particle size will be within the range of 0.1 to 10 micrometer, sorry where 0.1 to 1.0 micrometer. Whereas, superfine powder is being defined as 1 to 10 micrometer and granular powder is defined as 10 to 100 micrometer, whereas this granular solid will be within the range of 0.1 to 30 millimeter and broken solids which are being very high in size in range that is 3 to 10 millimeter range.

So, these are the powders that you can classify and based on these classification of the powders of course, the performance of the fluidization depends. Of course, these way this is one of the way to classify the powder there are other way that is very common that is called Geldart classification of powder.

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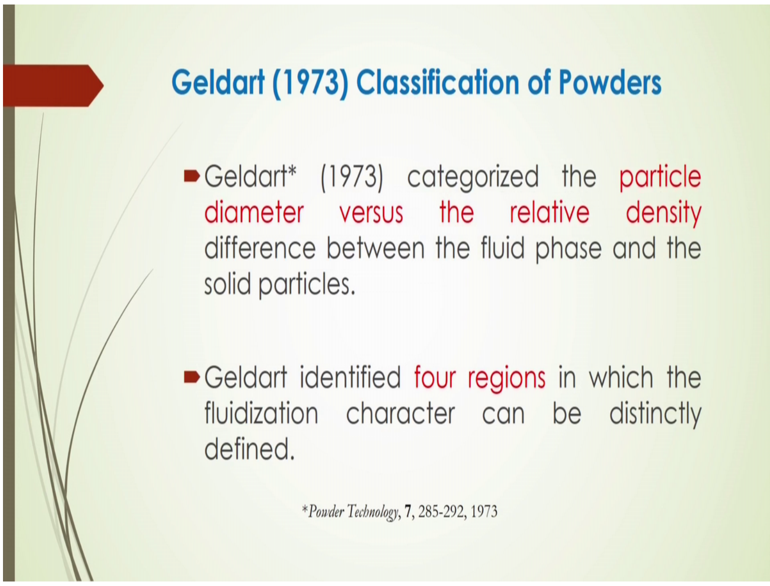

Geldarts 1973, he classified the powders based on the particle diameter and the relative density difference between the fluid phase and the solid particle. And he categorized these powders into 4 regions in which the fluidization character can be distinctly defined.

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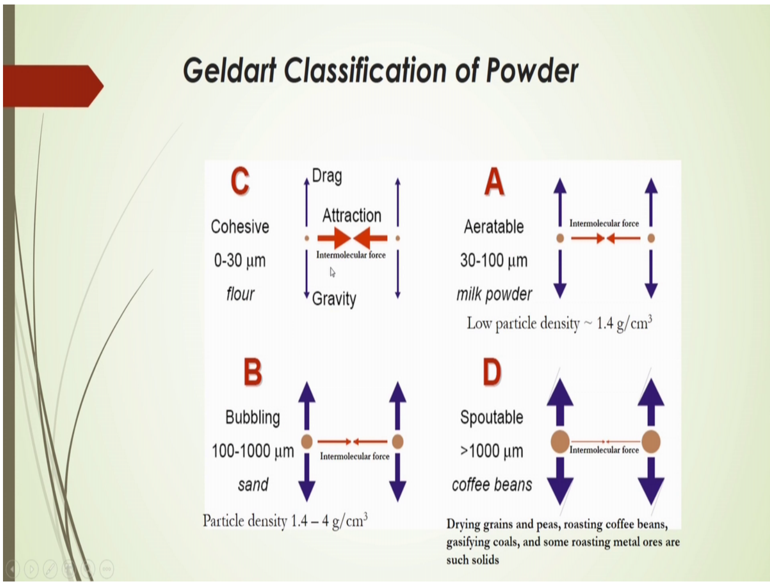

And he actually reported this 4 types of classification and denoted by C A B and D.

Now, C means what? This is very cohesive in nature; that means, fine particles are there very fine particles are considered in this case the particle size will be 0 to 30 micrometer like example flow. Now, this 4 particle; that means, since the particle size is very low;

that means, they are inter molecular force between the solids particles that is fine particles are very high and because of which the cohesiveness nature will be there. And this vender walls force are more dominantly acting on this fine particles.

Another type is called A type particles. This A type means aeratable, aeratable here A is for aeratable and C for cohesive. This aeratable particles actually will be within the range of size range of 30 to 100 micrometer here of course, the intermolecular force between the particles will be relatively lower than the cohesive type of particles.

In this case like example milk powder and the density of the particles will be almost equal to 1.4 gram per cc. So, in this case since the particle attraction that is intermolecular attraction, or inters particle attraction is relatively lower. In this case the particles which are moving upward in the fluidized bed there will be a particulate bed formation not exactly that some bubbles will be forming some other very space that is porosity will be more higher, and of course, there will be no clogging formation said the bed that is not obtained by this aeratable type powder.

Whereas beat a powder; that means, here the bubbling formation inside the bed if you are working with this bit a particle, now bubbles will form and to be going upward and during this upward movement of the bubble at the top of this power, at the top of this bed these fine particles would be swipe away from the surface and. So, bubbling phenomena will be occurred by this B type powders, B here bubbling for B. So, the size range of the particles of this powder will be 100 to 1000 micrometer like sand. Here also the particle density will be within the range of 1.4 to 4 gram per cc.

Now, another term that is D type particle, D type powder. D type sphere means spoutable in this case the particle size will be is greater than 1000 micrometer like coffee beans. So, with this D type of particles it is generally being suitable for fluidization operation for drying or gains, even a drying, a peas roasting of coffee beans, even gasification of coals, even roasting of metal ores. So, these operations in the fluidize bed of course, you have to choose the particle size within the ranges of these D type powders so that you can get easily the spoutable pattern of the fluidized bed and it will be suitable for drying purposes. That is physical operation are very spoutable for D type a powders, with D type powders.

So, these are basically 4 types of powders are classified by Geldart 1973. So, based on these different types of powders the performance of the fluidize bed will be actually estimated and also the efficiency of the fluidize bed depending on this particle size and also other factors. Now, what we told that there will be some intermolecular force. So, intermolecular force between the particles of course, there will be high for queasy when lower than A lower for B type and then even workforce beta even work for D type particles.

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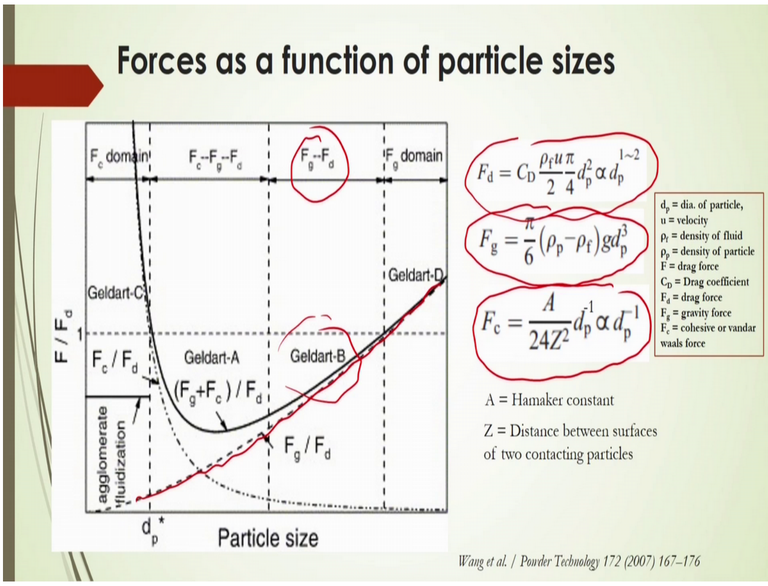

Now, how these forces acting depending on the particle size for different fluidization operation even the ranges of the fluidization operation based on this attraction of this intermolecular particle attraction and. Now, how it will be related? Generally 3 types of courses are acting (Refer Time: 24:48) bar the fluidization operation is being done with these particles of 4 types. Now, those are F d, F d means here drag force and F g F g here it is called gravitational force and also c is called cohesive or Van der waals force.

Now, F d, this F d here this F d is of course, this F d is related to the a particle diameter this particle diameter of course, to the power 1 to 2 it varies and g gravitational force of course, depends on the cube of this particle diameter and F c, Fc means cohesive force it depends on the particle diameter. Now, how it will be? Depends that is inversely proportional to the particle diameter if you increase the particle diameter you will see the cohesiveness will be reduced. But if it is size is reduced then more cohesive force will be there intermolecular force Van der waal force will be more higher compared to the other forces.

Now, these 3 forces if you add then this total force that will be represented by F. So, here this F d is drag force it is nothing, but C D into rho f u by 2 into pi by 4 d p square; that means, here this is F d drag force is directly related to the fluid density and the velocity of the fluid and of course, the projected surface area of the particle. Now, C D is called drag force it will be discussed later on how it is related to the velocity of the fluidization operation and of course, it will be related with the Reynolds number of the operation it will be shown later on.

Now, this gravitational force of course, is the relative density of the fluid and the particle and F c is called quasi force that is inversely proportional to the particle diameter this related by this A by 24 z square into d p to the power minus 1. What is a is called Hamaker? Hamaker constant and z is called distance between the surface of the two contacting particles.

Now, here see this F by this relative force that is total force relative to the drag force in the y axis and in the x axis is called particle size. Now, how it will be related this graph how see if saw total force is decreasing. Total force is decreasing initially for a particle diameter up to certain value and then it will increase and it depends on the particle that is powder type for Geldart C type particles you will see this total force will certainly decreases very steeply when particle size increases. But for the other types of like delta b and delta d type particles they are you will see different other forces the domain of the other forces will be in such a way that it will be higher like F g minus F d in the b type particle F g minus F d. Here in this case you will see within this region there will be certain variation of this with respect to particle size. Whereas, this F g by F d it will be increasing with respect to particle size here and it will be lower for Geldart A part, A type particle where it will be higher in Geldart B type particle higher to be Geldart B type particular is be more higher.

Now, in this case another type that is called if suppose the particle size is very low; that means, here d p in this case the tendency to make the agglomeration in the fluidization operation that is with c type particles. So, is F c by F d in that case it will be higher relative to the other particles. In this case d p star is at a particular certain diameter by means you can get that there are some forces cohesive forces or F d force or F d force are similar.

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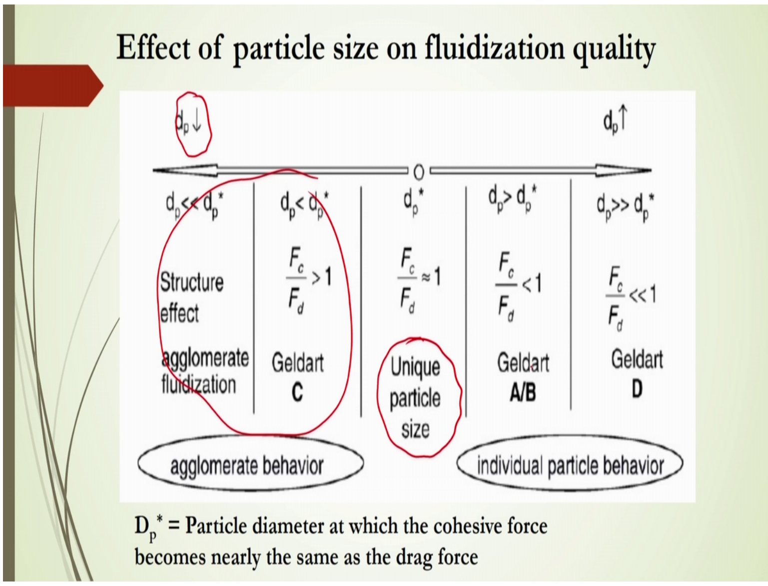

Now, particle diameter at which the cohesive force becomes nearly the same as the drug force it will be represented by the d star. Now, this effect of particle size and fluidization quality how it will be depending. Now, you will see if you reduce the, if you reduce the particle size here if you reduce the a particle size; that means, d p if for less than that d p star then you will see there will be effect of structure of the particle, even how where the how what is the shape of the particle that is very important because there is a cohesiveness nature some surface will be made in such a way that the two surfaces are joined together in such a way that the cohesiveness force is acting, acting and it will very difficult to separate out. So, agglomeration phenomena will be in hence there and dominate in this case.

Whereas, if d p just slightly less than d p star in that case like delta c type particles here the cohesive force will be more or greater than F d that is drag force here. So, still here cohesiveness nature will be pertaining. So, agglomeration behavior of course, pertains in this region, this region. Whereas, at the d p star; that means, here particle diameter at which the cohesive a force cohesive force are equal to the drag force in this case unique particle size of course, will be represented by this phenomena when these two forces are equal.

So, in this case you will see either you are getting the cohesiveness force behavior or some other behavior like in the individual particle behavior, in this all the particles will be moving separately from each other. So, this is the transition point or transition force by which you can get the fluidization operation that is called particulate bit. It is just sliding the particles from each other without making any agglomeration whereas, if d p is greater than d p star in that case you will see that cohesiveness force will be less than the drag force. There drag force will be dominating in that case fluid particle interaction will part in and if you are using the mixture of A and B particles they are you will see more suitable fluidization occurs. But they are of course, the liquid slurry system, liquid and solid slurry system there if you use high viscous fluid then again there be a drag force will be more higher more higher and because of cohesive you will see some phenomena of the fluidization will hindered.

And then if you increase particle size; that means, here if more greater than d p star then that case the drag force should be far far higher than that cohesiveness cohesive force or bender wall force. In that case intermolecular attraction forces will be very low and this happened only for D type particles like for drying operation that is why the drying operation will be feasible this type of particles because there will be a separate movement of the particles possible in the fluidization operation without making any agglomeration.

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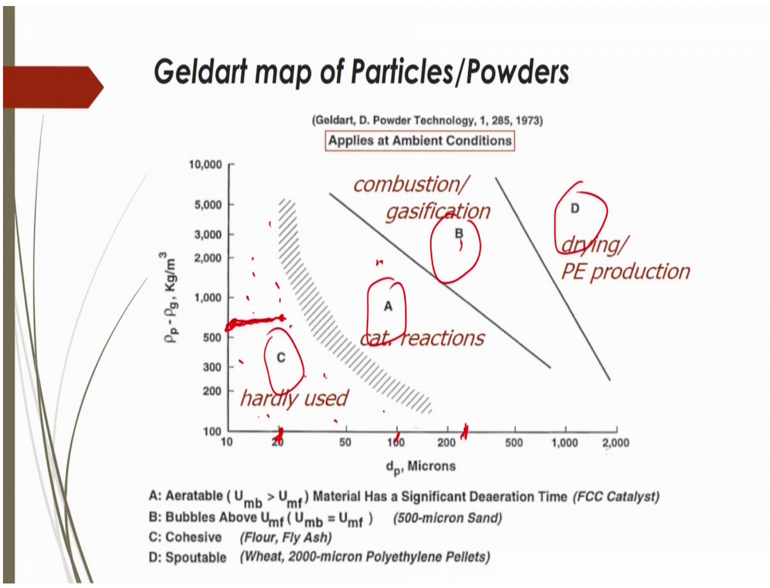

And then of course, we can then based on the performance of the fluidization which region or which particles will give you the better fluidization operation that also can be obtained. Now, based on the Geldart powder classification they have actually make they made a one, they made one map by the by considering the relative density of the particle to the fluid and the particle diameter.

The y axis see here the relative density is particle diameter to the gas diameter sorry gas density to particle density here rho p minus rho g, here rho p means particle diameter and rho g means gas density rho p means density of the particle. So, in the x axis is d p the particle diameter and here some regions of C regions A regions B regions and D regions these are the regions based on this relative density.

Now, this C regions at any point if you just consider here you will get the you will get the C type particles; that means, if particle diameter is 20 micron and if you are considering here these 20 microns the dense relative density will be somewhere here above 500 kg per meter cube. Now, these regions will refer the C type powder and it is hardly used for your fluidization operation. Whereas, catalytic reactions will fever in case of a type powder in this case the since the cohesiveness nature of the powder is less than this C type, so it will be more useful for catalytic reactions and event for combustion and gasification reactions will be more favorable for B type and for drying and other poly ethylene production D type products are.

So, this is one map from which you can calculate which at which region you are going to if any you are having any particle with a size then you and also what will be the relative density in which medium you are going to operate the fluidization, then you can obtain of course, which fluidization operational to which particles will be favorable. Like if you are having the 100 size particle micrometer and you are using the some gaseous medium, in gaseous medium of density of different and particle relative density here then you can say it is the A type powder and it will be most favorable for catalytic reactions. Even also if you want to do the combustion gasification the favorable reason B then you can get of course, if you are having the relative density of the powder and what would be the particle size you can make it 200 micrometer then it will be favorable for you to do fluidization.

So, A means here aeratable whereas, minimum fluidization for bubbling will be greater than minimum fluidization that is U mf and material has a significant deaeration time for the like FCC catalyst and for B type like bubbles above U mf. That means, minimum velocity for fluidization for bubbling will be equals to minimum fluidization velocity like based on 500 micrometer sand it is suitable for bubbling and C means cohesive flour fly ash, D means spoutable wheat, 2000-micron polyethylene pellets these are the examples.

So, Geldart they made a map of particular powders based on the relative density and the particle diameter in this way. So, it will be helpful to identify which particles to be suitable for getting what type of fluidization phenomena. Now, let us discuss the characteristics of the different group of particle for its operation for fluidization.

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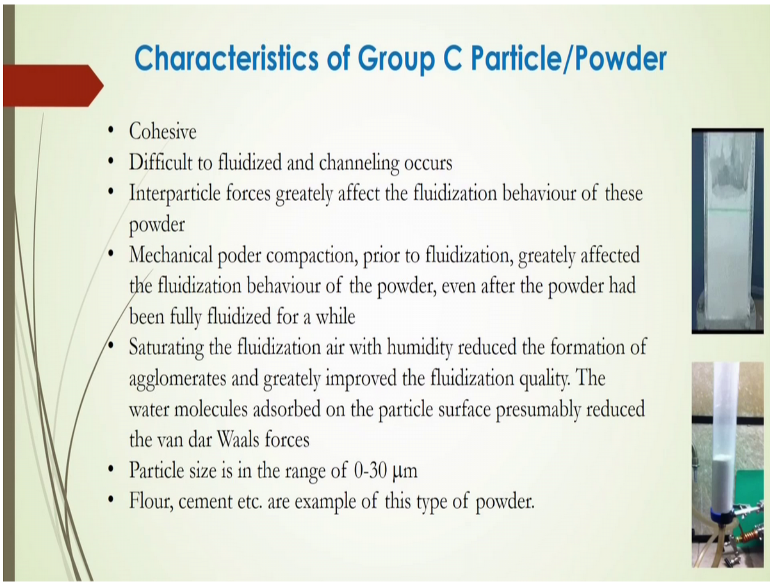

You see characteristics of group C power particle that is powder you can say. So, this is cohesive a nesser that is very difficult to fluidize and also the channeling occurs channeling occurs you see here in this video, there you see how channeling occurs here in this case just see the video one video here see fluidization occurs and then this chunk of solid particles is moving up and then it will be collapsed and after that it makes the channeling through which the gas is flowing upward.

So, this happens because of the very cohesiveness of the particles. If you increase the gas velocity you will sees the channeling will be more channeling will be forming and also the depth of the channeling will be of course, change. And here you will see another operations you have seen this fluidization. In this case the interparticle forces how it will actually affect the fluidization. And also other characteristics like this mechanical powder compaction even prior to prior to fluidization, greatly affected the fluidization behavior of the powder, even after the powder had been fully fluidized for a while.

So, and also you will see another important aspect of this characteristic of group C is that saturating the fluidization air with humidity because this type of particles will carry more moisture and it reduced to the formation of agglomeration and greatly improved fluidization quality. If you make the saturation level in such that is minimum moisture contained in this particle then you will you can improve the fluidization by just lowering the agglomeration phenomena inside the bed. And of course, this C type powder in that powder particle size will be in the range of 0 to 30 micrometer, like example flour, cement etcetera the best example for this type of particle.

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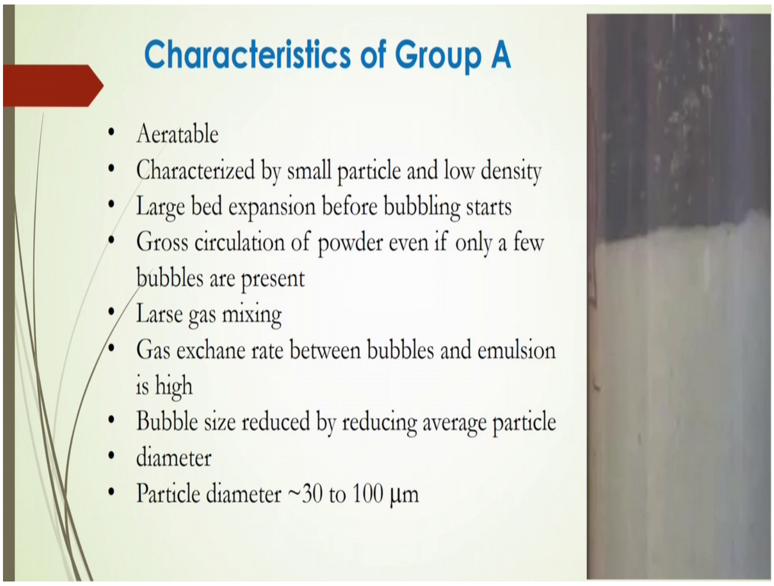

Now, characteristics of group A, here see what video here see how this fluidization occurs this group A type particle the size range is 30 to 100 micrometer, here this particulate bed fluidization occurs. Here there is no you will see bubble formation during this operation and the surface of the bed is tilting and also there will be a and this is aeratable because you will see gas will be or air may be will be passing through the solid space in the bed easily, the smoothly the gas is passing through the space of the solid. So, that is why it is called aeratable.

And here of course, characterized it characterized by the small particle and low density if you have the more density then you will not get this particular type of bit. Large bed expansion before bubbling starts of course, you will see there will be a bed expansion will see some bed expansion video. And gross circulation of the powder even if only a few bubbles are present here you will see these particles gross circulation of the powder you can get here.

Large gas mixing of course, you will get for better fluidization operation the mixing of course, is one important phenomena and gas exchange state between bubbles and emulsion or of course, will be very high in this case. And bubble size is reduced by reducing average particle diameter and then the particle size of course, will be within the range of 30 to 100 micrometer. So, this is the characteristics of the (Refer Time: 41:33) for this of course, that you can say that this type of group A is very important for catalytic reactions.

Now, bubbling that means, characteristics of group B what is that it will be bubbling; that means, whenever you are working with this type of particles for fluidization you will get the you will see the formation of bubbles will be there. That will bubble forms with a certain diameter, after the size of the bubbles will change and at the bottom of this fluidized bed the size of the bubbles will be lower.

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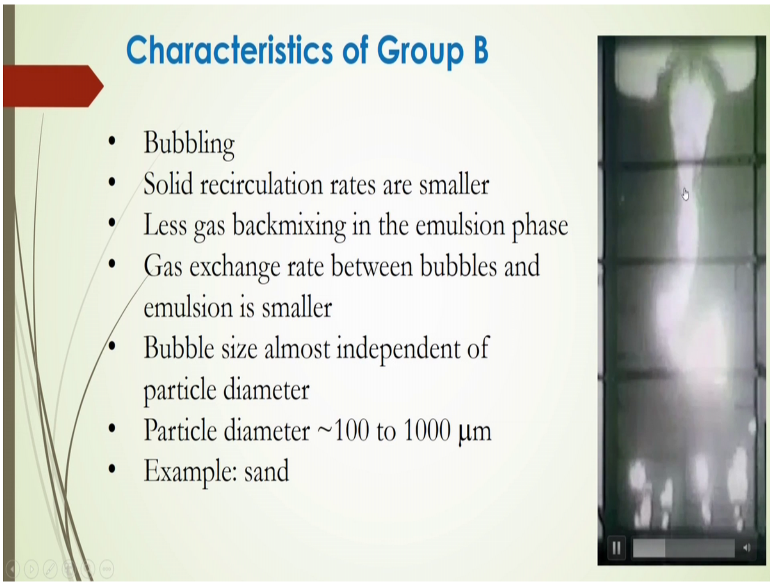

Whereas, whenever it will be coming up as per this video here bubbles will be a moving up and two bubbles whenever it will be coming to each other there will be a coalitions of these two bubbles and make it a bigger bubbles. And at the top of this surface of this fluidized bed you will see the bubbles are just breaking into our collapse in such a way that solid particles will be swept away from the label.

Now, this is basically this bubbling fluidized bed yeah, solid particles of course, you have to use within the range of 100 to 1000 micrometer. If you use a more than 1000 micrometer you will not get this type of bubbling phenomena and of course, cohesiveness cohesive type or particles also you cannot get the bubbling phenomena only this type of particles within a certain operating range you can get it.

So, solid recirculation rates of course, will be a smaller in this bubbling phenomena and gas back mixing of course, will be lower in this case because bubbles will be forming and it will be a carrying the particle or, every the particle in the one direction and gas exchange rate between the bubbles and emulsion will be smaller. If you increase the diameter of the column of course, the back mixing may enhance of course, exchange of these particles and the bubbles of course, will be there. A gas exchange means suppose some particles some gases will be inside the bubble and also inside the particle, then there will be a chance of exchanging the gas between the particles and emulsion of course. And of course, the inside the bubble sometimes some gas of course will be there, there also there will be exchange of the gas phase from the bubbles to the emulsion.

Now, bubbles size almost independent of the particle diameter. If you are increasing the particle there may not be changed the bubble size there. Particle diameter will be within this range like sand particle if you are making the same particulate within the range of 100 to 1000 micrometer and may make the fluidization with a certain velocity above this minimum fluidization velocity then you will get this type of bubbling phenomena fluidized bed.

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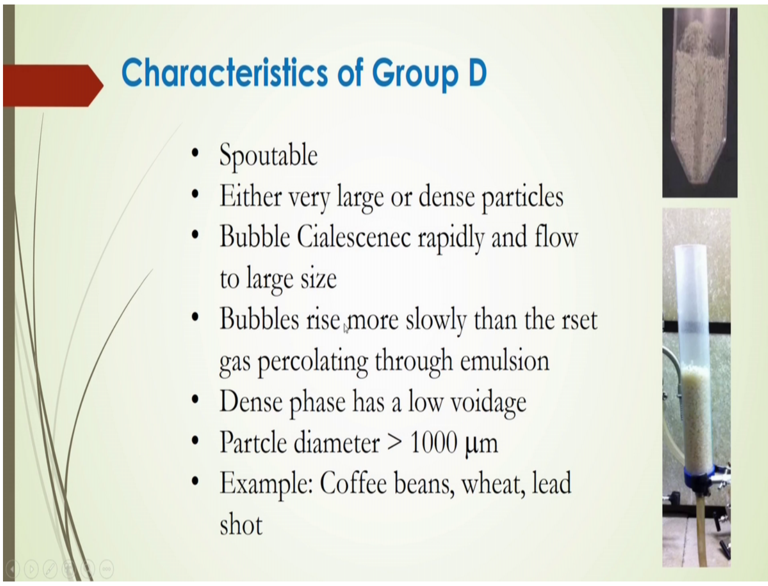

And the characteristics of group D that is called spoutable type of fluidized bed you have see this video how spoutable phenomena is coming. Here see, important through the center of the bed the gaseous is just coming out just making a channel with a certain diameter and see how, but in this case you will see the solid particles also moving downward at the exhausting to the wall of the column.

Now, in this case the spouting you have see how this gas or you can say that solid particles will be moving upward in such there will be like you will that is a fall of like solid particles and making the spout like this. And in this case of course, the character is either very large or dense particles you can use or bubble of course, coalitions rapidly and flow to large size of course, will be there. Bubbles rise more slowly than the gas percolating through the emulsion, if your den space has a low viodage and particle diameter of course, will be greater than 1000 micrometer like coffee beans, wheat and lead etcetera.

In this case this figure see how this a group D particles will be fluidizing here this video also will show you or this nice fluidization operation you will see. This is of course, with a particle send particles with what that these detail particles, you can do this operation with coffee beans wheat also if its size is greater than 1000 micrometer; that means, by 1 millimeter in size. You will see it is there one, see for low velocity of the gas will see there will be no a fluidization operation this is almost fixed bit condition after the certain velocity that means, if you increase the velocity beyond its minimum velocity you will see the fluidization operation will occur.

Now, this starts to the fluidization operation here and the gas is very hard to flow this gas through this particle, but of course, it will be there of course, you have to maintain the gas velocity in such a way that the gas will be flowing through the space of the solid particles and making a spout like this. This is of course, see this in the video how this fluidization occurs.

Like above picture also the same way this with a peddy that had been, it has been done and then this spoutable nature is formed in this picture. Other important thing at that before going to that fluidization operation different forces that (Refer Time: 48:25), now how these forces will be balancing and from who is how to calculate the drag force and drag coefficient is very important to know.

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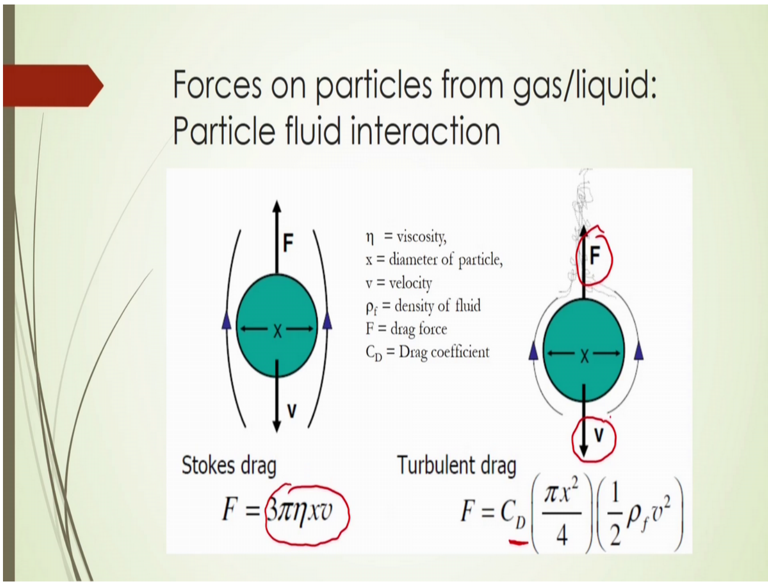

Now, forces on particles from gas or liquid that is particle fluid interaction is very important aspect of fluidization you have to know the different forces in different regions of flow rate, different ranges of flow rate if you are operating the fluidized bed very low flow velocity then it is called of course, Reynolds number if it is less than 1, it is called stokes range of operation; that means here the drag force would be higher that case it depends on the viscosity of the fluid and the size of the particles of course, other important factor is the velocity.

Now, since in stokes range the velocity will be the terminal velocity or settling velocity and in that case what will be stokes drag force that will be calculated by 3 phi eta xv, where is it eta is called viscosity, v is called velocity and x is the characteristics length of the solid particle. If it is spherical of course, this characteristics length will be diameter of the particle. And here in this case for turbulent drag if suppose the Reynolds number is greater than 1, even more than Reynolds in this case particle Reynolds number of course, we are talking about if it is not the stokes condition then you will get this drag force as that depends on the surface area of the particles and the kinetic energy acting on the particles. This kinetic energy is half of rho v rho F v square and C D is called here the proportionality constant of this kinetic energy by which you can get the drag force it is called drag coefficient. So, this turbulent drag you can calculate by this equation as C D into pi x square by 4 into half of rho of v square. This is rho f is the fluid density.

Here see here this balancing of this force F and v here, this F is that is drag force is acting upward, whereas this velocity if it is that will be in the downward and also the settling velocity will be acting downward here, that is in favor of gravity it will be acting.

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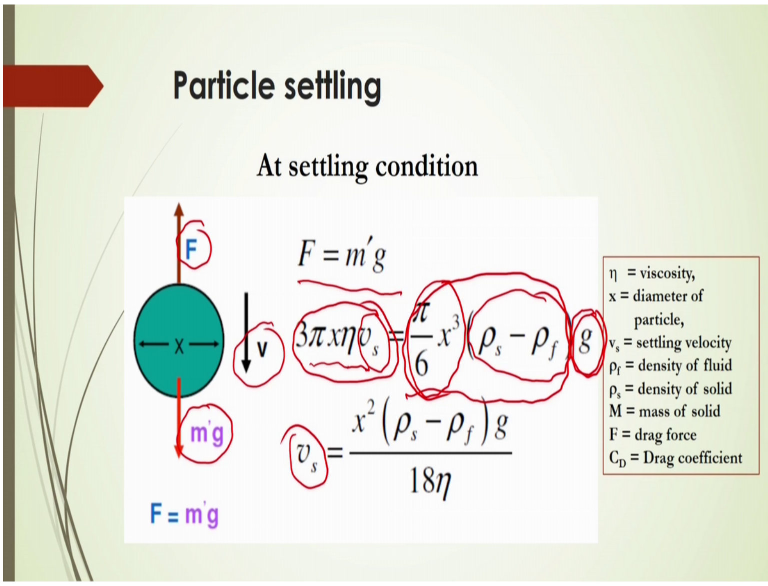

Now, particle settling of course, at settling condition you will see the balance of these two forces one is called drag force or you can say and the stokes drag force and another is called gravitational force that is m into g. This m, this mass of the particle and this g is the gravitational acceleration and then F is equal to m dash to g and where the settling velocity is v which is represented by v s, s for settling. So, here stokes drag force is 3 pi x eta into v s and that would be equals to your apparent weight of the solid particles. This apparent it will be calculating as pi by 6 x cube, this is the volume of the particle and then what will be the relative density of the particle that is rho s minus rho f into g. So, this is called mass of the solid and this g where it will be weight of the solids.

So, this is stokes drag force will be balancing by this weight of the solid. So, from who is you can calculate what will be the v s, v s means settling velocity. So, at the equilibrium condition; that means, that when the solid particles will stay by balancing these two phases or two forces then you can of course, easily calculate the settling velocity from this equation.

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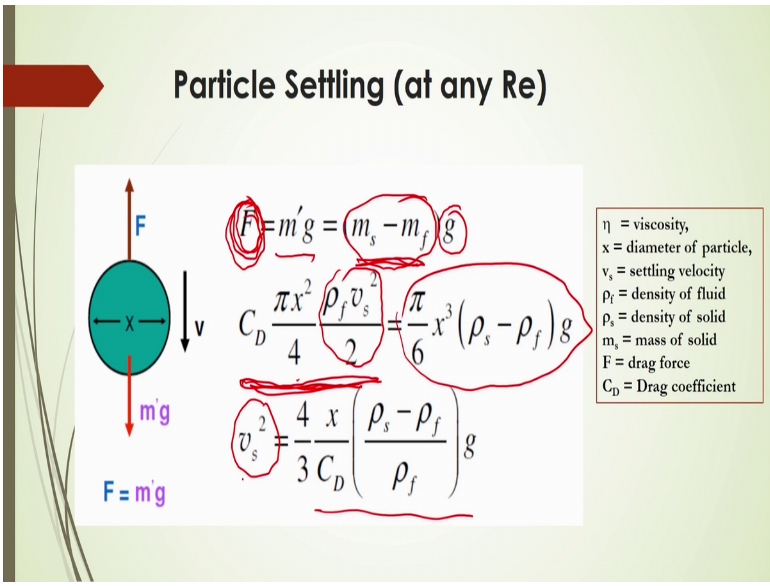

Now, here Reynolds number of course, will be less than 1, but if Reynolds number is greater than 1 or if suppose Reynolds number will be more higher or at any Reynolds number you can say beyond this stokes condition you can calculate this settling velocity like this here balancing these two forces. What are this balancing two forces here? F is the force acting on this particle whenever it will be a moving inside the bed and then it will be calculating as m dot m dash to g here m dash is nothing, but here relative mass of the a solid compared to that fluid here m s minus m f, m s means mass of the solid, f means mass of the fluid. So, here this is the relative mass and our effective mass of the solid into g that is gravitational acceleration. So, this will be equals to total effective weight of the solid when it will be moving with any Reynolds number.

Now, from this equation you can calculate just substitute the value of this C D; that means, this force will be calculating this is not as the stokes drag force this is that other than a drag force, other than strokes drags force this is at any Reynolds number it will be depending on the kinetic energy of the fluid by which these solid particles is moving. So, in this case it will be C D into phi x square by 4 into rho f v s s square by 2. So, that will be equals to this effective weight of the solids.

Now, from this two forces you can calculate this v s squared equals to this. So, v s will be is equal to root over of this. So, you can directly calculate what will be the terminal velocity or you can say settling velocity of the solids at any Reynolds number from this equation.

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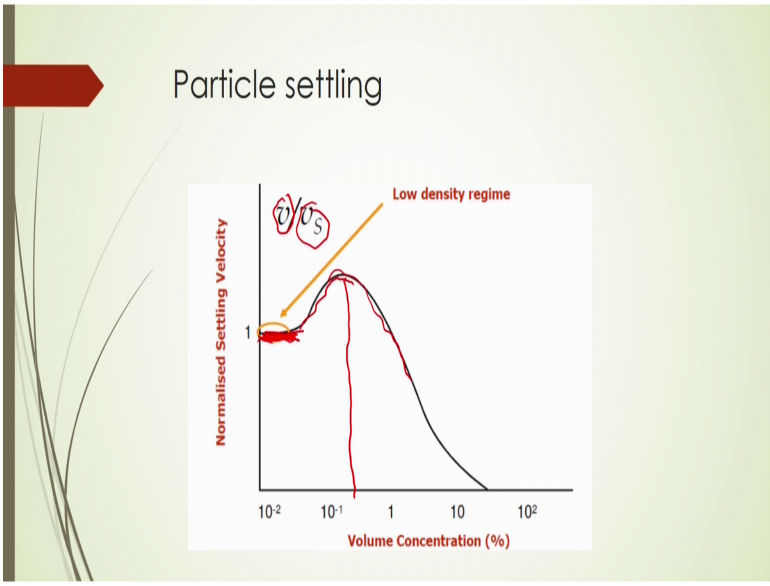

Now, see particle settling if you are representing this particle settling velocity normalized particle settling velocity suppose at any velocity, if you are operating the fluidization operation with this solid particles what will be the velocity of the fluidized fluidization at which this fluidization occurs that is represented v and what do the settling velocity then v by v s it is called normalized settling velocity.

Now, at low density region you will see this little v t; that means, normalized settling velocity does not change; that means, here the volume concentration if you are maintaining very low then there will be no change of this normal settling velocity here and normal setting. But increasing the solid concentration or volume concentration in the fluidized bed you will see there will be a peak of this normalized at a certain volume concentration whereas, this peak will decrease, this peak will decrease gradually if you increase the volume concentration. So, this normalized settling velocity will be changing with respect to the volume concentration.

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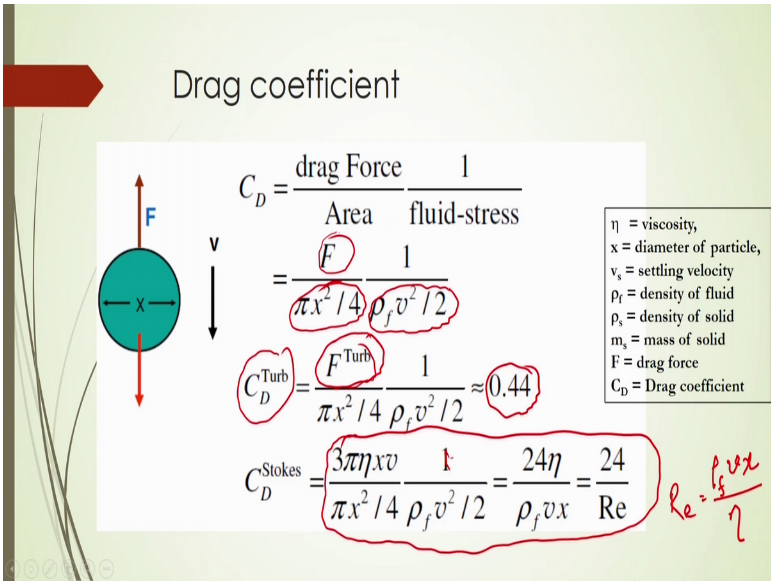

Now, drag coefficient how to calculate just balancing the drag force and the effective weight of the solid in the fluidized bed from which you can get the drag coefficient. So, drag coefficients it will be equal to drag force by area why what will be the fluid stress is there. So, drag force is F and this area this is projected area that is pi x square by 4 this x is the characteristics length or diameter of the particle and this is the fluid stress is nothing, but the kinetic energy here rho f v square by 2.

Now, this C D for turbulent flow of course, this will be F will be is equal to turbulent condition, at turbulent condition what will the force drag force is applied and this is generally remains almost constant at 0.44 a turbulent conditions whereas, and the stokes range of the operation that is Reynolds number if it is less than 1 you will see this drag coefficient will be, will be is equal to 24 by Re. How it will be here. What will be the F turbulent? This is nothing, but 3 pi eta x v divided by this is pi x square by 4 into 1 by rho f v square by 2 that will be equal to just after rearranging you can get it 24 eta by rho f v x this is 24 by this Reynolds number.

This Reynolds number is nothing but, this Reynolds number is nothing but here rho f density of the fluid into velocity of the particle at which it moves not settling velocity here and into characteristics length divided by eta; that means, viscosity of the medium. If it is gas then gas density, gas viscosity if it is liquid of course, it will be the liquid viscosity.

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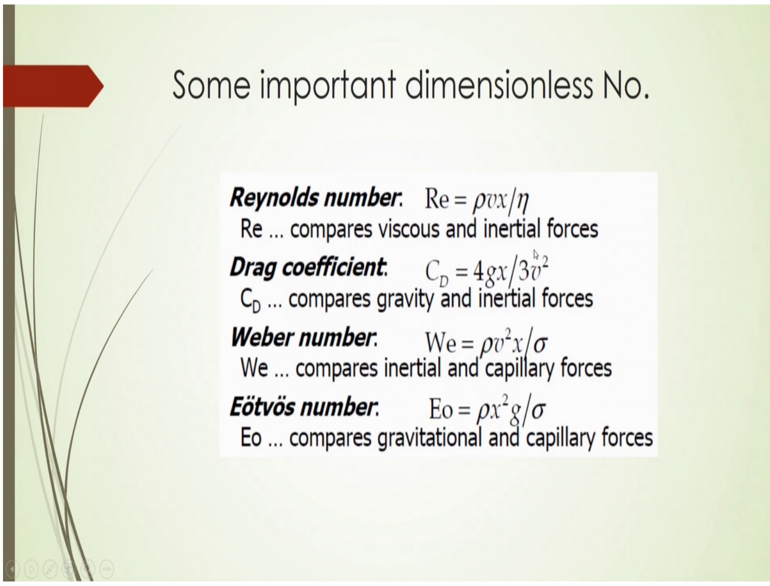

So, this normalized settling velocity will be changing with respect to the volume concentration some important dimensionless number of course, populization operations is important here like Reynolds number, drag coefficient, Weber number, even Eotvos number. These are actually very important dimensionless improved by use you can express the fluidization phenomena physically.

Now, Reynolds number if a response is of course, this is a ratio of inertia opposed to the viscous force, but they are fluidized bed you will see whether inertia force will be dominant to the viscous force or not. Of course, if you are operating the fluidized bed with the gas flow then of course, inertia force will be higher than the sorry inertia force will be higher than the viscous force. And here C D this drag coefficient actually signifies the ratio of drag gravity to inertia of force whereas, Weber number it will give you is there any surface tension effect is there or not. So, Weber number is nothing but the ratio of inertia force to the surface force or surface tension force or capillary force you can say.

Inverse number will give you the ratio of gravitational to the capillary force of course, by which you can say whether the quadratic part of that shape of the bubble will be there, what will be the whether it will be circular or whether it will be the elongated bubble will be forming that depends on the surface tension and also other size of the particle even other operating conditions.

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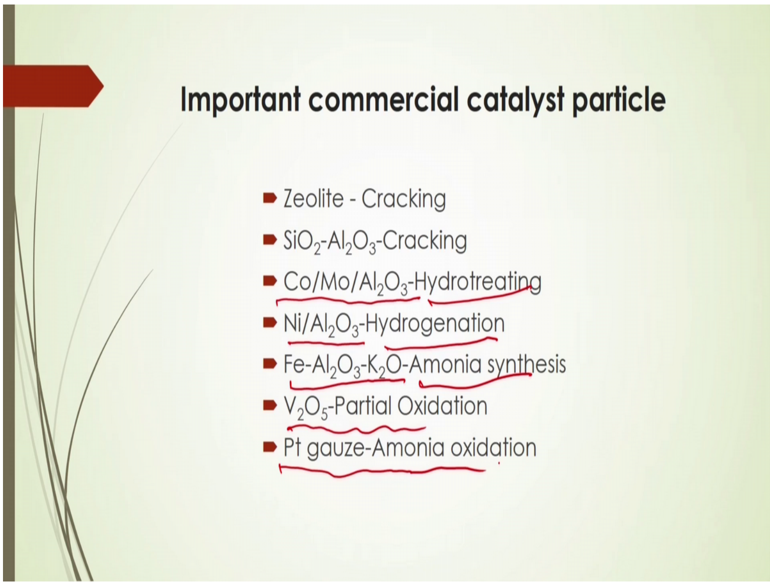

Now, important commercial catalyst particles that zeolite, cracking, for cracking operation, silicon dioxide and aluminum oxide mixture that is for cracking operations cobalt molybdenum and aluminum oxide this is suitable for hydro treating, even nickel aluminum oxide hydrogenation operations important. Iron aluminum oxide when potassium oxide these are very suitable for ammonia synthesis fluidization operation. Vanadium pentoxide is most important for partial oxidation and even platinum gauze is used for amonia oxidation in fluidized bed.

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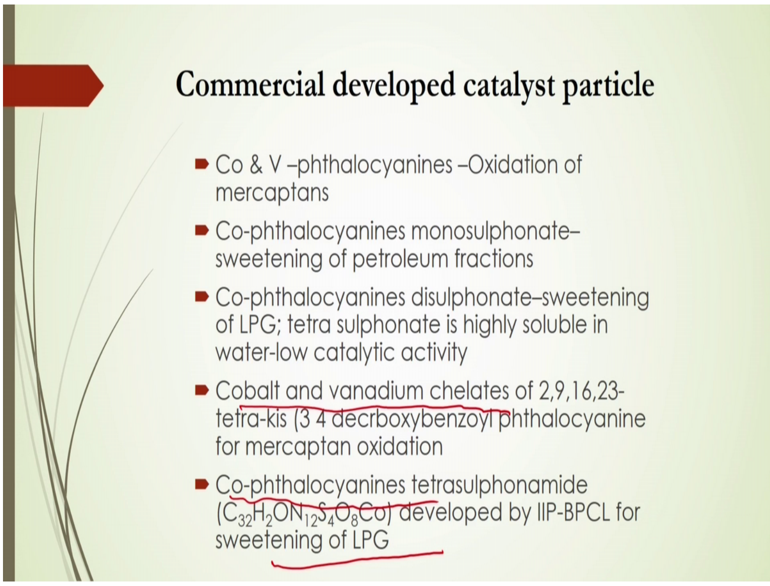

Some other commercial are developed catalyst particles are cobalt vanadium, even cobalt thiocyanates, even other different derivatives of this cobalt formation, cobalt and vanadium chelates like this cobalt phthalocyanines, thiocyanates, this type of commercial develop catalyst particles are being used in industry.

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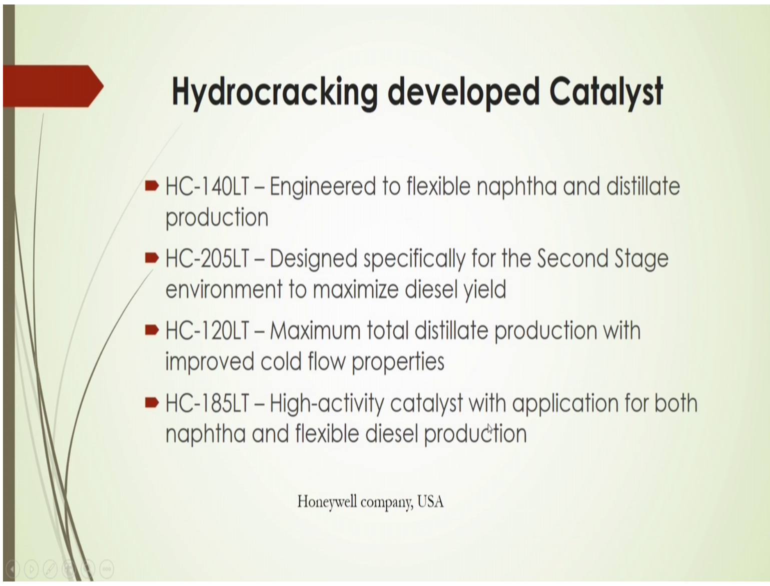

Hydrocracking developed catalyst like HC-140LT, HC-205LT, HC-120LT even HC-185LT, generally it these are being used for in Honeywell Company for their hydro cracking in fluidized bed.

Thank you.