Fluidization Engineering
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Lecture – 02
Particle Properties and Classifications

So welcome to this massive open online course on fluidization engineering. Today; the lecture 2 on particle properties and classifications. So, in fluidization particle properties and it is classifications play an important role for the behavior and also the performance of the fluidization in a fluidized bed.

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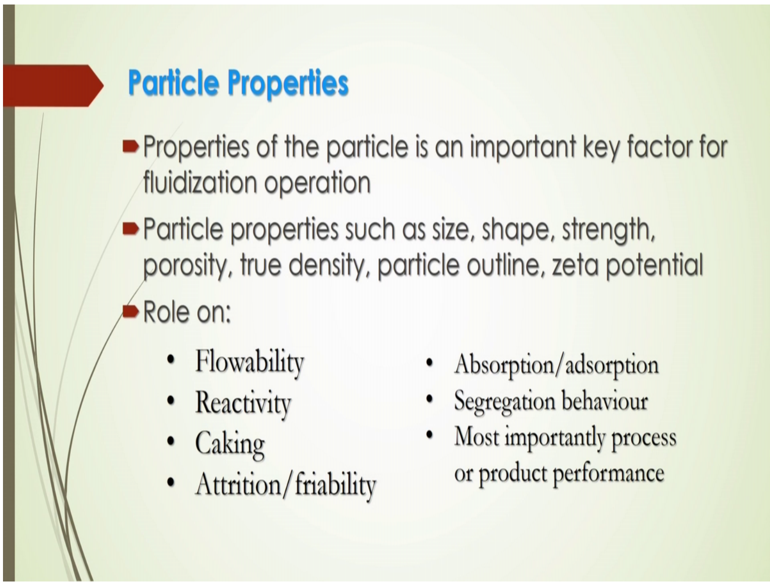

So what is this actually particle properties? So, particle properties is an important because you know that the different sizes shape and strength and true density particle outline also zeta potential acting in such a way that the mobility of the particles inside the bed that will governed the efficiency of the fluidized bed also different size of the particles shape also important for that.

So, you see that this properties like; size, shape, strength, porosity, true density and acts the roll on flow ability, reactivity, caking even segregation behavior in the fluidized bed what should the absorption and adsorption characteristics that depends on the particle properties, what is the caking properties inside the bed? And what should be the attrition and friability of course, it is very important for the fluidization. So, we have to know these particle properties before starting the hydrodynamics of the fluidization engineering or in a fluidized bed of course, we have to know.

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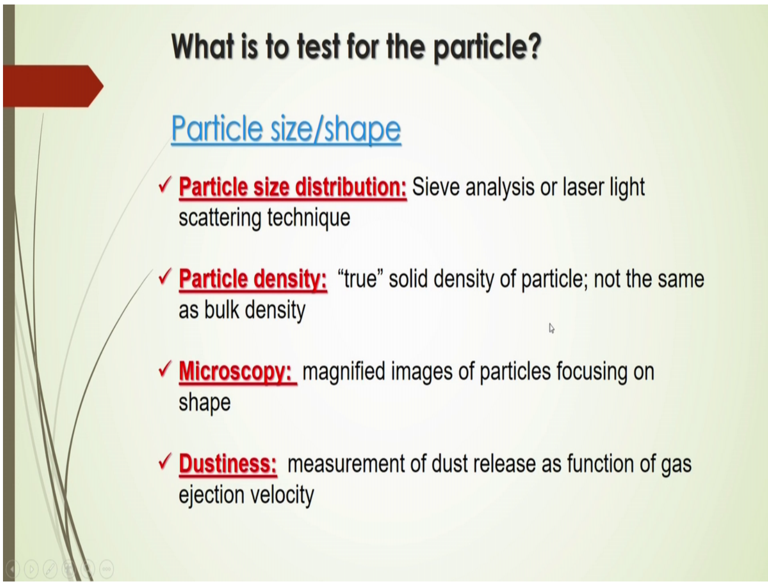

And what is the test for particle? So, that you can know what should the size of the shape what should be the size and shape of the particles? And what should be the distribution of the particle? And also what should be the particle density? How this particle density will behave? All these things to be known, so particle size distribution actually being done by sieve analysis or laser light scattering technique. Whereas particle density of course, you cannot use a bulk density for the purpose specific purposes mostly it is being used as a true solid density of the particle for analysis.

And also what should be the? What should be the shape of the particles that can be obtained by microscopic just images? You have to take some images from the by microscope and then analysis what should be the shape and also size also you can analyze by taking the image by microscopy by enlarging or magnifying the images and analysis by some software. And also another important property of the particle which is called dustiness will give you the whether these particles will make any dust; that means, here if any fine particles are forming then a dust reformation of course will be there.

In that case because of the ejection velocity that dustiness will create problem and also sometimes clogging and coagulation also possible for a particular fluid velocity by it is ejection through the distributor and all different type of distributor that can be used in the bed. Now it can be measured in such a way that that what should be the gas ejection velocity depending on the gas velocity it will be measured or estimated the dustiness.

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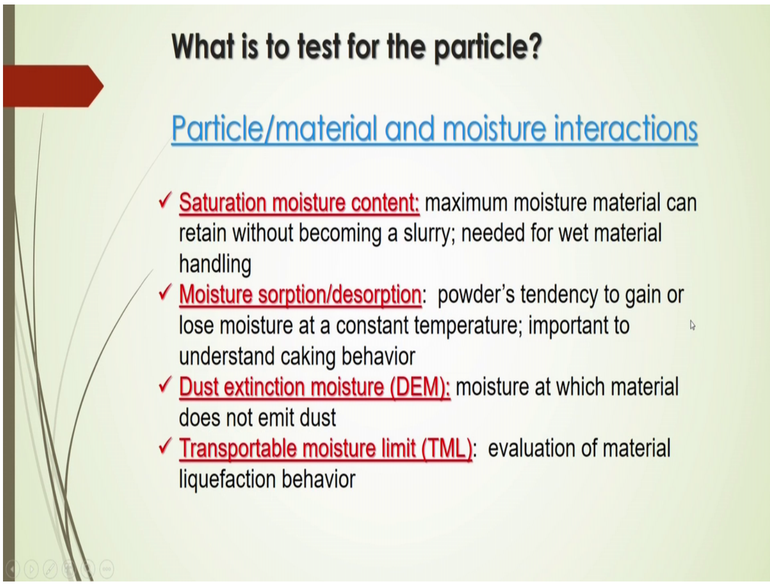

And also other properties like; what should be the particle and moisture interactions of course, any particle whenever it is being used in fluidized bed will contain some moisture. What will be the equilibrium moisture that contains the particles? And also what should be the other properties of the interaction of the moisture with the particles? You will see some other properties like saturation moisture content what should be the saturated moisture contained in the particles and also it should be needed to know because the maximum moisture material can retain without becoming a slurry, so it is required to know for particular analysis, and also moisture absorption or desorption is very important factor here you will see powders tendency to gain or lose moisture at a constant temperature and is it is important to understand caking behavior.

And another important factor is dust, extension, moisture so it is nothing but the material the property material property by which you can say whether this material will emit dust or not. So, moisture at which this moisture does not emit any dust this is called dust extension moisture, another important factor is called transportation moisture limit of course, this transportation moisture limit will evaluate the characteristics of the liquefaction behavior of the material. So, these are the important properties for particle moisture interactions or to know the characteristics of the particle and these are like suspicion moisture content moisture sorption or desorption you have to know, dust extinction moisture you have to know and transportation moisture limit also you have to know.

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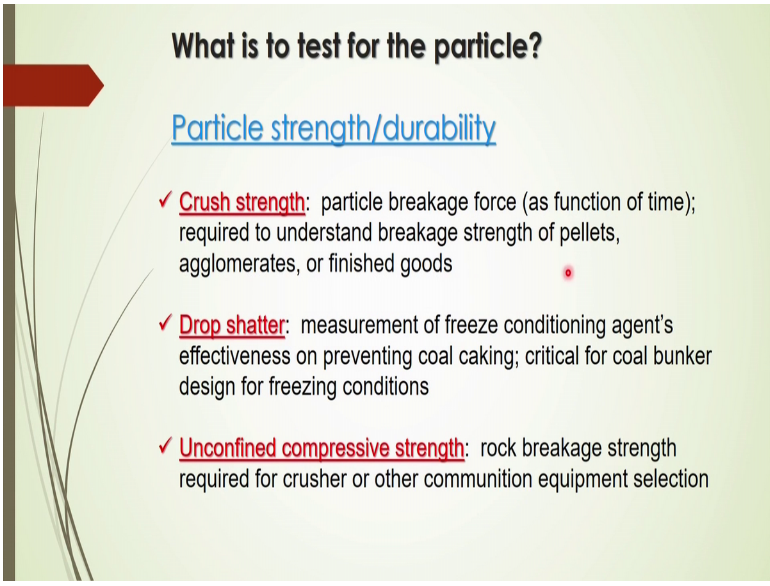

You will see some other properties like; particle strength and durability it depends on particle material of course, the durability of the particle of course whenever in fluidization operation particles will be used you see sometimes the particles will broken down at a high a velocity, so in that case the strength of the particle is important for this purpose. Now a particle breakage force as a function of time required to understand breakage strength of the pellet us whatever it is being used whether this is the this will form any agglomerates or any finished products will be good in nature or not that also will be depending on the a strength of the particles.

So, if it is more strength; then of course, it will be the particle breakage will be less. So, here sometimes you will see the finer particles you will see to break it very problem whereas, the hard particle it is the some particles are easily broken down some particles are you are not that much extinction of durability what it is to it is original condition.

And drop shatter, your measurement of freeze conditioning agent's effectiveness on preventing coal caking is very important here. Critical for coal bunker designed for freezing conditions with draft shutter is very important factor for the fluidization, now unconfined compressive strength this is another important properties of the particle strength, so you see the rock breakage strength required for crusher or other communition equipment selection. So, unconfined compressive strength you have to measure before starting the fluidization operation.

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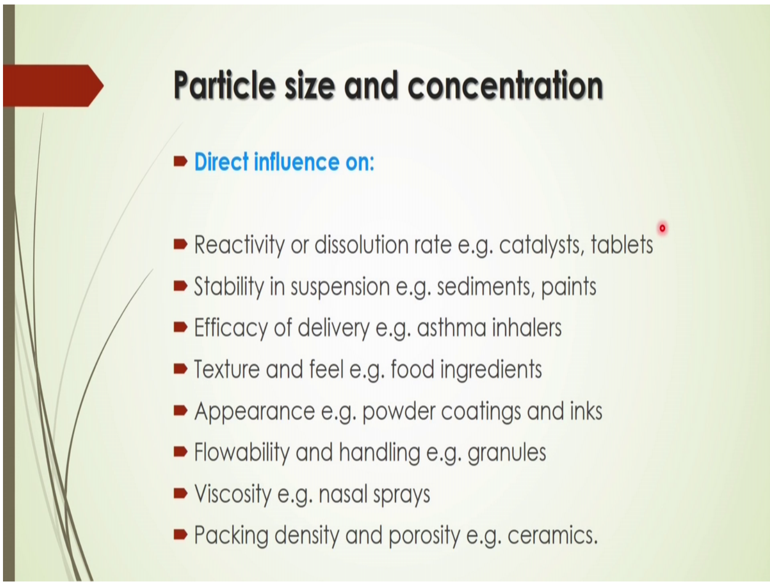

Another important this is very crucial factor that particle size and the concentration, because you will see the size of the particles will make what should be the flow ability of the fluidization. Now, different patterns of the fluidization depends on this size; if there is a smaller or finer or it is a coarser particles you will see different pattern of the fluidization behavior characteristics that changes based on the particle size, sometimes very fine particles is not suitable for fluidization sometimes some coarser particles are being actually suitable for specific application in the fluidization operation, you cannot use where very coarser particles that will be very tough to fluidized also very fine particles also it is not suitable because it makes some cohesiveness nature or making a clock inside the bed or you can say agglomeration formation also this sometimes possibility there to in the fluidization.

So, this particle size and it is concentration has direct influence on reactivity or dissolution rate like; catalysts and tablet's in that case these are used for reactivity or dissolution rate in the fluidization operation.

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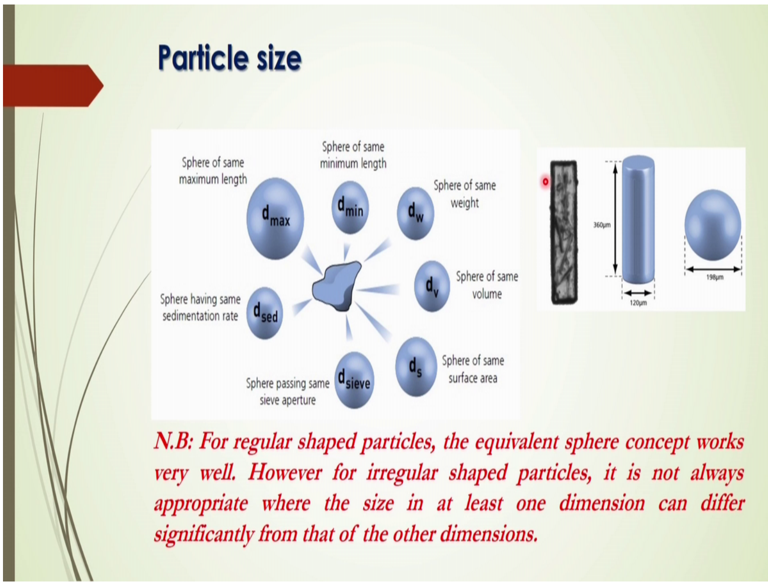

Another ok, important thing is that; how you will represent the particle size? There are different way to represent to the particle size like here sphere of same maximum length sometime it is being used to represent the size of the particles, you will see sometimes the minimum particle diameter as a sphere of the same minimum length it is being represented to show that flow behavior needs in the fluidized bed. And also sphere of same weight; of course, you will see if you are using the particle of the same weight and what will be the size of the different particles? and if you are using the same weight then sphere of the equivalent same weight it will represent what will be the size of the diameter also diameter or size of the particle.

And also sphere of same volume, it is represented by the same volume of the sphere if you are represented in what will be the equivalent diameter of that particle. Also sphere of same surface area it is very important you are just comparing that it different shape of the particles are there we are comparing that the surface what will be the surface area and if you make it the equivalent spherical surface area then what should be the size of the bubble that you can represent it? That is represented by d s.

Another important sieve sphere passing the same sieve aperture, then what should be the aperture of the sieve? That represented by the particle size also or this type sieve aperture will represent the particle size, generally we are measuring in the operation mechanical operation lab how to measure the particle size by the sieve or screen. And however for irregular shape particles it is not always appropriate where the size in the so as where the size in at least one dimension can differ significantly from that of the other dimensions, here see one figure here this is the one shape of the particle see here this is rectangular, this is cylindrical and this is spherical.

So, all these different shape of the particles you will see you have to make it one equivalent size of the sphere, so that what should be the diameter of the sphere and if you make the same volume or by same surface or by maximum length or minimum length or the sphere having the same sedimentation rate, if you are using this type of concept to make the equivalent particle diameter you can have. So, we will show later on that what should be the different definition of the particle how to measure? And how to estimate the different mean of the particle we will show later on.

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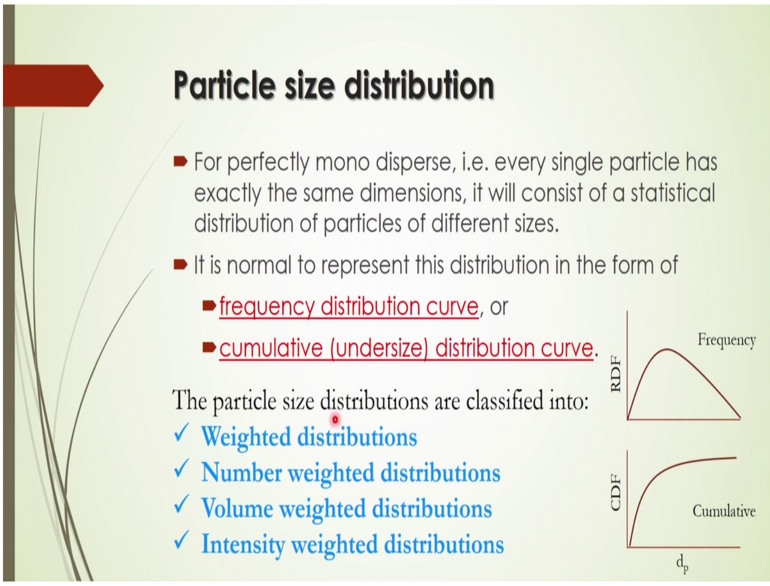

And then particle size distribution of course, for a mixture of the feed you will see if you solid particle feed is there you will not get the same all the same size in the mixture. So, there are different sizes of the particles will be in the mixture, may be within a certain range.

Now what should be that? What should be the number of particles within a certain range of the size, if you divide the different classes then you will see there will be a different number of particles will be under in the certain classes. So, if you make it n number of classes, what will in each classes in each classes within a maximum and minimum actually aperture or you can say a diameter range you will get certain y number or z number of a particles will be there. So, for perfectly mono disperse in that case every single particles has exactly the same dimensions if you are using, it will consist a statistical distribution of a particles of different sizes, it is normal to represent this distribution in the form of sometimes in frequency terms and some sometimes in cumulative terms.

This is here frequency terms the x axis it will be in your diameter of the particle in y axis it will be the RDF, RDF means a relative density of the frequency here what will be the suppose particle up in a particular bean at in a in a particular class, how many number of particles out of total number of particles then it is called a relative frequency function or the cumulative density frequency function that is called. So, here in this case you will see the distribution will be like this and from this distribution you can say in which particle diameter will have the maximum number of particles inside the in the sample.

And also cumulative representation of the distribution is important in this case; in this class what will be the number it will be just summing of successively and then it will be represented as cumulative distribution function and the function will be profile the functional profile will be the lie with these and here that is. So, is our particular particle diameter what should be the, a number of particles also you can obtain from the distribution. So, the particle size distributions are classified into; weighted distributions, number weighted distributions, a volume weighted distributions and intensity weighted distributions, this intensity weighted distributions means suppose if you are by analyzing the particle size which it is certain color for a certain color any image or dynamic way, then how this intensity of the color will change according to it is size of this particle it will give you the; some distribution.

Volume weighted distribution is also important what will be the volume of that particular size of the particles will give in a percentage that is number weighted distributions like what will be the number in a particular class of the particles that will be given by a distribution. And weighted distributions of course, it will be what will be the weight? What are the mass percent's of the, a solid particles in a sample that will be represented by a distribution. So, this is very important if you are having all the size are same in the sample then you will get the only one line distribution of the particles; whereas, if there is a mixture of different sizes particles you will get this type of distribution.

So, if suppose this distribution is very narrow. What does it means? This; all the particles will within the very short range of the particle sizes if it is wider in range; that means, here the sample consists the very minimum to the very maximum sizes of the particles in the sample. So, from the distribution you can obtain what will be the particle, this particle size distribution is very important for analysis the hydrodynamics or flow behavior of the particles or any process yield that depends on this particle size distribution.

If you are using more finer particles of course, the surface area of the particles will be more in that case the catalyst activity of the fine particles should be more there may be mass transfer will be more; whereas, the but larger particles or medium size particles there if you use there will be see some heat transfer operation mass transfer operations even some other drying operations also it will be more favorable. So, you have to know what should be the particle size distribution ok.

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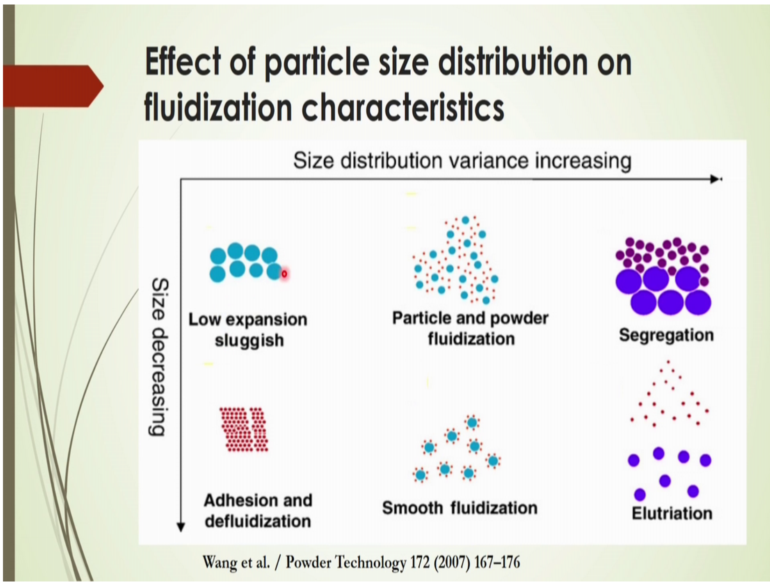

So, this is the important for the fluidization operation. If we see this diagram size distribution variance here increases and here it is size decreasing. What does it means? They are the two x scales, if I represent the fluidization characteristics you will see if we just consider this one this is low expansion sluggish. What does it mean here? Size of the particles is very high whereas, the size distribution of variance will in a low. So, in this case the low expansion sluggish inside the bed will be there; that means, sluggish will be more whereas, so there will be no expansion of the solid particles is possible inside the fluidized bed.

Another important aspect is particle and powder fluidization where you will see the size distribution if it is there is a mixture of different sizes particles you will see, the size distribution will vary size distribution will vary in that case the wider size distribution may possible, but all the particles are very smaller in range, so in that case it will exist here, but it may change if you decrease the size, so in this case whatever size if you decrease the even more finer particles as a more finer you will see a more smoother fluidization you can obtain relative to this fluidization in this case.

And also here, if you consider these very bigger particles mixed with a finer particle, in this case the segregation in the fluidized bed will be feasible and that means, easily you can segregate these particles, so that this distribution will be in this case you will see some bigger particles should be and smaller particles the distribution will be in such way that you can easily identify this particles, what would be the this particle? What would be this particle? What is the fraction of this particle?

What is the friction fraction of this particle from the distribution itself you can easily identify, at a different location if you measure the a size distribution of course, if you take the samples and also analyze then you will get the size distribution and from this size distribution you will be able to say this sample will have more finer particles or these samples will more will have more coarser particles. So, in this way you can segregate the solid particles by fluidization by taking it is or analyzing it is size distribution. Also you will see if you decrease the size even more; that means, here if the less than suppose 30 micron what will happen the cohesiveness of the particles will be there, because intermolecular attraction will be more in that case the fluidization is very difficult.

So, for finer particles very finer particles if you have all the finer particles are the same in size the particles the size description will be narrower. So, in that case for finer particles with narrower distribution it will be it will not be suitable for fluidization whereas for whereas, it can be suitable if you just mix with some other coarser particles with that there will be intermolecular attraction will be changed and also if you use different size different nestled particle also likes of positive or cationic particles of course you will use, you will see sometimes the positive ion particles or ion particles will will bind with the negative ion particles and there it will be fluidize.

So, in that case some specific example of the fluidization it may be a suitable for having this type of particle size distribution with this cationic and anionic particles also, sometimes elutriation is very important here important in that case also you have to know how much elutriation is possible from the bigger particles or if you initially use all the bigger particles and after elutriation after broken down of the particles and if you analyze that how much solid particles are being broken down and what will be the size distribution of that? Then from these you can at least interpret what should be the elutriation rate? What should be the elutriation efficiency? You can analyze it by the particle size distribution.

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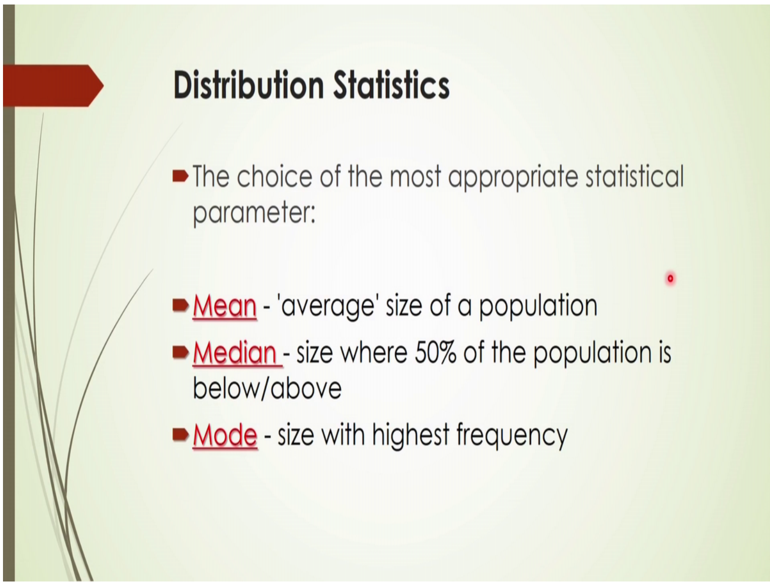

And for the distribution of course, you have to analyze something not only the simple distribution, no it will not be simple distribution. Here you have to know what should be the mean of that particle size or over a size of the population that you have to move what should be the median size where 50 percent of the population is below or above that you have to know and also another important statistical parameter is called mode the size with highest frequency of course, you have to know. If you are having the highest frequency; that means, that particles will be more in number in the sample and also means sometimes these lower range to higher range if you are making mean; that means, if you there are different type of means you will get; sometimes arithmetic, sometimes surface mean sometimes volume mean volume surface mean there are different types of means definition will be shown later on, but you have to know what should be the mean size of the particles by which you can analyze the further efficiency or simulation purpose or modeling purpose you have to know the particular size of the particles ok.

So, you have to use the mean size of the particles. So, the so this statistical parameter for the size description you have to analyze by mean made in and more, these are the most important statistical term there are some other statistical parameters are there, but so these are the these threes are being mostly used for a fluidization purpose.

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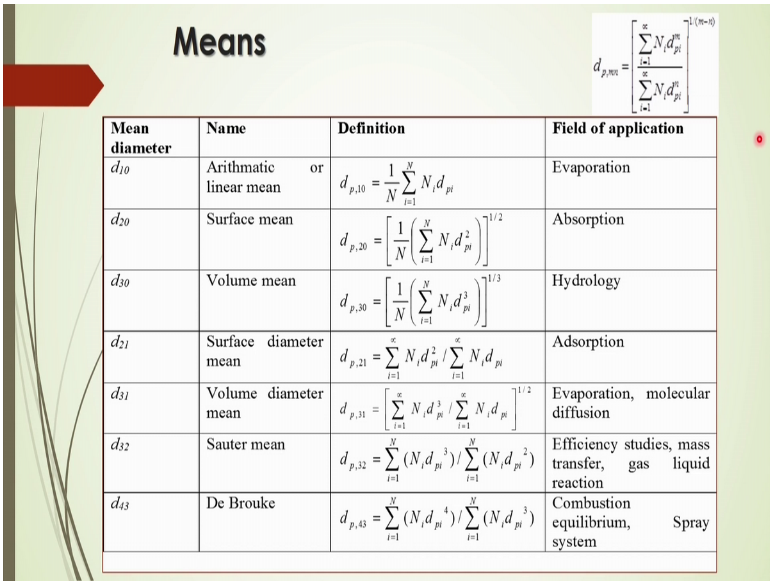

Mean diameter	Name	Definition	Field of application
d_{10}	Arithmatic or linear mean	$d_{p,10} = \frac{1}{N}\sum_{i=1}^{N} N_i d_{pi}$	Evaporation
d_{20}	Surface mean	$d_{p,20} = \left[\frac{1}{N}\left(\sum_{i=1}^{N} N_i d_{pi}^2\right)\right]^{1/2}$	Absorption
d_{30}	Volume mean	$d_{p,30} = \left[\frac{1}{N}\left(\sum_{i=1}^{N} N_i d_{pi}^3\right)\right]^{1/3}$	Hydrology
d_{21}	Surface diameter mean	$d_{p,21} = \sum_{i=1}^{\infty} N_i d_{pi}^2 / \sum_{i=1}^{\infty} N_i d_{pi}$	Adsorption
d_{31}	Volume diameter mean	$d_{p,31} = \left[\sum_{i=1}^{\infty} N_i d_{pi}^3 / \sum_{i=1}^{\infty} N_i d_{pi}\right]^{1/2}$	Evaporation, molecular diffusion
d_{32}	Sauter mean	$d_{p,32} = \sum_{i=1}^{N} (N_i d_{pi}^3) / \sum_{i=1}^{N} (N_i d_{pi}^2)$	Efficiency studies, mass transfer, gas liquid reaction
d_{43}	De Brouke	$d_{p,43} = \sum_{i=1}^{N} (N_i d_{pi}^4) / \sum_{i=1}^{N} (N_i d_{pi}^3)$	Combustion equilibrium, Spray system

Now, what is the mean of a different particle? That is being used for fluidization that you have to know, what is the definition of the means here? you will see a mean diameter you can define in different way, general equation of a defining these it is like; d p m N is equal to here summation of N i d p i to the power m divided by summation of this you are see or in this equation N i d p i to the power N to the power 1 by m minus N.

What is p? P for particle; d for diameter and m for these coefficients m for some other coefficients, so I want to infinity means here individual particles; number 1, number 2, number 3, number 5, n number of particles will be there. So, if there is n number of particles and if each particle will have it is own diameter like; d p i i-th number of particles will have the diameter of d p. So, in that case if you are defining this d p mean like here, if you are considering that mean diameter. What will be the mean arithmetic linear mean? Arithmetic linear mean is defined by m is equal to 1 and N is equal to 0 so; that means, here a d p 1 0, d p 1 0 means here it will be as per this general definition here 1 by N is equal to sum into summation of what is that? Are summation of I is equal to 1 to N, N i to d p I, here this is called arithmetic mean similarly d 2 0, d 3 0, d 2 1, d 3 1, d 3 2, d 4 3 these are the different a notation for the define definition of the mean of the particles in a sample.

So, some are d 1 0 it is called arithmetic linear mean, d 2 0 it is called surface mean, even d 2 1 it is called surface diameter mean, even d 3 2 it is called Sauter mean, even d 4 3 it is called d broke mean and also d 3 0 is called volume mean. And this arithmetic mean here it is a respective definition is given in the slides. So, how it will be defined? and also all this mean diameter actually for analysis, for different processes are being used specifically like; arithmetic linear mean generally is used for evaporation purpose and d 2 0; that means, the surface mean it is being used for absorption, d 3 0 that is volume min it is being used for any hydrology of a processes and also surface diameter mean like adsorption, even volume diameter mean it is the d 3 1 it is I generally being used for analysis of evaporation or molecular diffusion with the samples.

And Sauter mean it is very widely used mean for the samples of different sizes particles, this is for efficiency studies of like mass transfer gas liquid reaction when gas liquid solid reactions in the fluidized bed, this particle mean are being represented by this Sauter mean this is b 3 2; that means, here volume to surface mean diameter, d 4 3 de broke this is also one important for fluidization this is for combustion if you are using combustion in a fluidized bed what should be the equivalent particle diameter is being they are produced then you can analyze by this a d 4 3, d 4 3 here; that means, here m is 4 and n for 3 here 3 4 volume even surface square; that means here ah, so this is defined in this way.

So combustion, equilibrium and spray system this means are very widely used, so these are the different definitions of the means you can use for different purposes, but whenever you are using fluidized bed that is the; d 3 2, d 4 3 and d this is d 3 0 these 3’s are very widely driven it is suggested to use for different operations.

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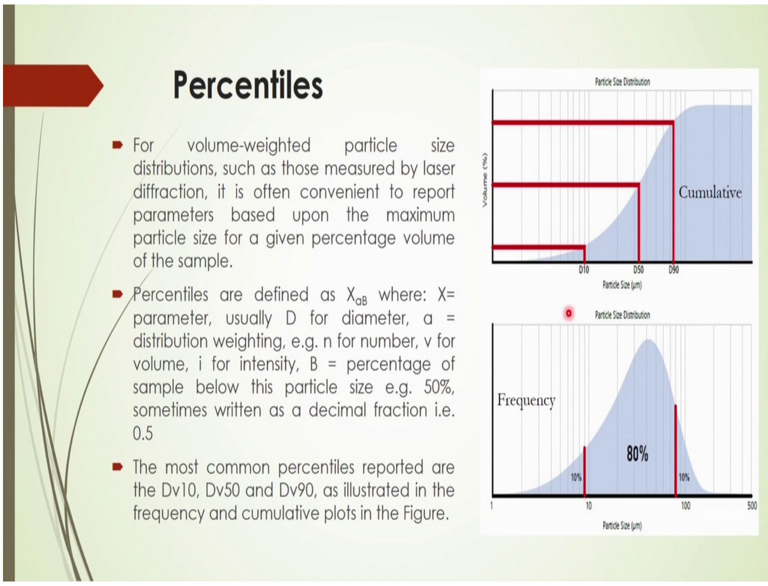

Now, another important to analyze that particle size distribution by percentiles, for volume weighted particle size distribution you will see such as those measured by lesser depiction it is often actually convenient to report parameters based upon the maximum particle size for a given percentage a volume of the sample here. Suppose in c particle size and this is volume person this particle size d 50 or d 1 0 or d 90 this nothing, but 50 percent d 50 here means fifty percent of the particles are volume percent is like this and also here d 90 percent of the particles are size in d 90 like this micrometer. So, percentiles are defined as X alpha B here alpha, so this X alpha beta where X is the parameter usually this is being used for diameter d for diameter and alpha is the distribution weighting example; suppose n for number here and v for volume I for intensity and beta is the percentage of sample.

Below this particle size example like 50 percents sometimes written as a decimal fraction that is 0.5. So, here very important the sample below this particle size example: 50 percents of this; that means, here within this diameter of the particles like X alpha B here in this case this particles represent the 50 percent of the volume of the particles will be a diameter less then this particle size. And here 90 percent of the in this case this 90 percent of the particles in the samples will have the diameter of the particles less than this d 90 ok.

Similarly, the most common percentiles reported are Dv 10, Dv 50 and Dv 90, as illustrated in the frequency and cumulative plots in the figure like this, here the this is the 80 percent of the samples will have the particle size and frequency over overall of the or the total volume is 80 percent of the volume will contain the number concentration of the particles the 80 percent or number concentration will be within this region of 10 percent to here 10 percent. So, this is the representation of the percentiles in the first particle size distribution, this is also one important sometimes if you are going to analyze the particle size by what is that the laser depletion method to like a million particle size analyzer they are also it is being analyzed by what is the volume percent? What is the number percentage? You can convert it from volume percent is to number percent to volume percent if you know the particle size also and within a certain range of the, what will be the percentage of the solid particles will be in the distribution that you can read from the distribution of the parameter.

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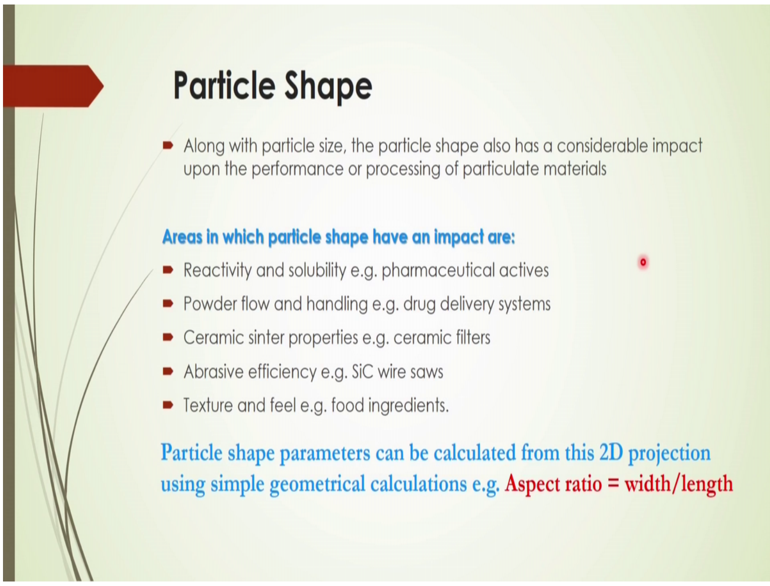

And then, this particle shape this is also important all the particles you do not get the same in size of course, some particles will be more in diameter even some particles will be the rectangular, some particles will be cylindrical, some particles will be only just rod like, some particles will be even irregular in shape, so these shape of the particles also very important to analyze the fluidization behavior in the fluidized bed.

Now, in that case how? this particle shape will also will effect on the flow behavior in the fluidized bed or performance of the fluidized bed like reactivity and solidity like pharmaceutical actives in that case also it may vary the reactivity because of the size of the particles, sometimes uniform particle size will mostly actually favorable for uniform mixing and also yield of the processes. And also ceramics inter property is important in that case if you use different shape of particles this center properties of course, will change and also powder flow and handling you cannot have the same a flow ability with a different shape of the particles.

Even you will see texture and feel, if you use the different shape of the particles the texture of the particles in the fluid as a fluid ingredient will be vary. So, particle shape parameters sometimes in the 2 d projections you can measure by the aspect ratio this aspect ratio is nothing, but what will be the width of the particles whatever be the length of the particle by which you can represent the particle shape or you can say the particle shape, you can see the particle shape parameter by which you can analyze the flow behavior inside the fluidized bed.

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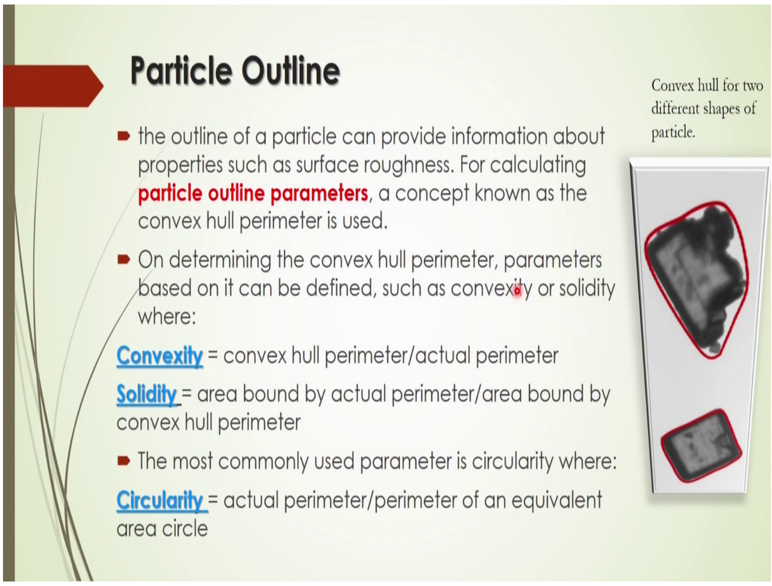

And then particle outline, the outline of the particle it will provide the information about properties such as surface roughness, for conducting particle outline parameters a concept known as convex hull perimeter is used convex hull perimeter you have if you know then by this convex hull perimeter will give you the outline of the outline parameter of the particles. Here see on the remaining the convex hull perimeter some parameters based on it can be defined such as; convexity or solidity, where this convexity is defined as what will be the ratio of convex hull perimeter and actual perimeter.

Suppose this is the irregular shape particles here, what should be the perimeter? Perimeter just considering the what is that, the picks of this hull of this objects, so just joining this point of this peak of this different actually point of this particles and what should be the perimeter this is called convex hull perimeter whereas, actual perimeter will be if you just go through this like it is exactly wherever is their curvature if you consider the length of that due to that curvature this will be the actual perimeter.

So, if you divide this convex hull perimeter by actual perimeter of the object then you will get the convexity, so this convexity is the one perimeter one sorry parameter or particle outline to represent. Another important is solidity that is defined by area bounded by actual perimeter by area bounded by a convex hull perimeter, so in this case what will be the actual perimeter of course, you can obtain the and from which you can calculate what should be the area covered by this perimeter.

And also what should be the area bounded by convex hull perimeter. So, those things are not same actually, so there will be area difference. So, what should be the area of this convex hull perimeter and area of the X 1 perimeter? If you just make it ratio you will get the solidity. So, this solidity of course, will be is less than of course 1, because this area bounded by the convex hull maybe is greater than the area bounded by the actual perimeter.

Circularity is also one important parameter used for particle characteristics, this circularity depends on the of course, that what will be the actual perimeter and what will be the perimeter of an equivalent area circle? So, if you are having this is suppose this is one object and this the what will be the actual perimeter and if you consider that this perimeter has a parameter of a circle then what should be the area of that circle, just making it as what is that? pi r is equal to this perimeter 2 pi r is equal to this perimeter and what is that area is pi r square. So, what would be the r of that? So, you can calculate the circularity from this portion.

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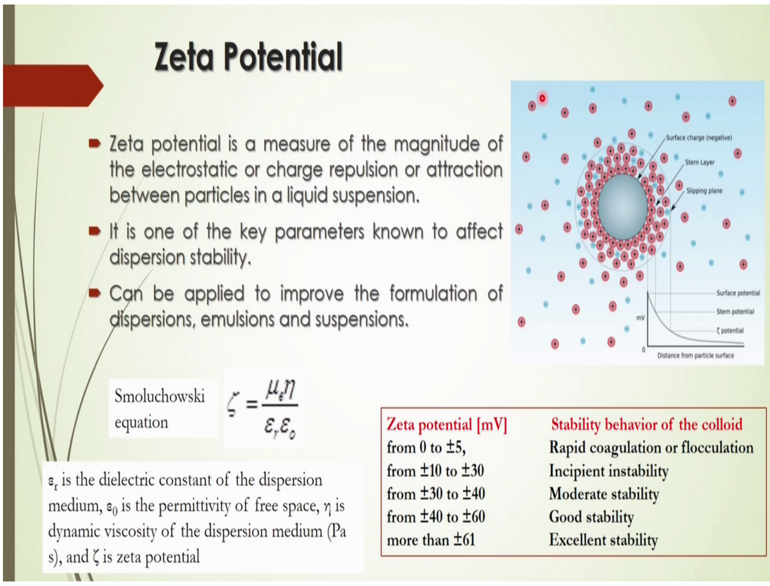

Now, another important zeta potential, this generally be used your; a liquid solid operations in fluidized bed or in gas liquid solid operation in fluidized bed, zeta potentialities are actually it will measure the magnitude of the electrostatic or charge whether it is repulsive or attractive, how much charge is there for repulsion and attraction between particles in a liquid suspension.

So, zeta potential will give you it is measurements now; that means, here this zeta potential will give you the what should be the magnitude or degree of the electrostatic charge which is being actually for the repulsion or attraction between the particles. And this is of course, important because sometimes the stability of the solid particles inside the bed for liquid solid or a solid liquid gas operation it is very important, because you have to anyway stabilize the system in a fluidize bed for stability for better dispersion or you can say uniform dispersion with stability you have to know this zeta potential.

And whether these particles will attract some other particles or not, it will make a coagulation or it will make any what is that bigger particles by conjugating with a negative charged particles or other charge particles that depends on the stability the potential, can be applied to improve the formulation of a dispersion, emulsion and suspension of course if you know the zeta potential you will be able to know how much dispersion will be there, how much emulsion what is the characteristics of the emulsions? What is emulsified? What extent of this emulsification is possible and also is it making any the stable suspension or not you can and you can interpret by the zeta potential.

Now, what is that zeta potential how to estimate that zeta potential? This zeta potential we are Smoluchowski equation is important here, that case the zeta potential is defined as mu e eta divided by epsilon r epsilon 0. What is mu e? Mu e is nothing, but mobility this mobility means here this whenever solid particles are kept in a solution whatever be this solid particles will try to move aside by attraction and repulsion of the relatively with other particles also. So, in that case if you are making it free there will be no mobility, if only due to the a settling velocity will move down, but if there is different sizes particles, different charged particles if you put into the sample what will happen one particles will attract another and another particles will repulse another particles

So in that way the mobility will change because of this nature of the ion of the particles. So, this mobility you have to measure and then, what will be the extent of that mobility? That can be measured by the instruments specific instruments are being used it is also which are size are also there are several equipment that is a standard method to measure this mobility and also what will be the viscosity? That is the eta is called dynamic viscosity of the dispersion medium in which the solid particles are dispersed.

And Xi is zeta potential and epsilon r and epsilon 0; epsilon r is the dielectric constant of the dispersion medium and epsilon 0 is the permeability of the free space. Ah. So, these parameters will give you the particularly the zeta potential, you will see there are some ranges of the zeta potential and what will be the effect of this range of zeta potential on the stability behavior of the colloid medium inside the bed. So, from 0 to plus minus 5, it may be plus it may be minus of course, based on the ion of the particles and also mobility. So, in this case 0 to a plus minus 5, it will give you the repeat coagulation or flocculation, from plus minus 10 to plus minus 30 you will see incipient instability and from plus minus 30 to plus minus 40 it will give you moderate stability, from plus minus 40 to plus minus 60 it will give you good stability, for more than 60 plus minus 60 it will give you the excellent stability.

So, if you are getting more excellent stability you have to use the particles in such a way that; that zeta potential will be more than 60. So, these are the here in picture the different particles of course, having different surges some positive some negative and whenever you are using an one surface charge is making and in surrounding this there will be a positive ion and even another layer if you are putting that the some other negative ion will come to this positive ion particles and there will be attraction and so there different layer by making a population of the different ions and from which you can obtain the mobility or potential of the particles, just from move one point to another point and from which you can be able to measure or estimate the zeta potential.

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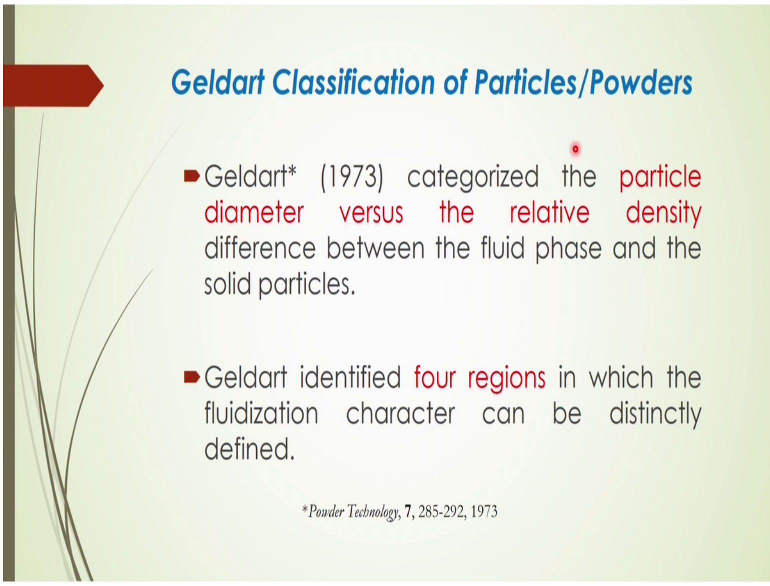

Now, important classification of the particles; now whatever particles that you are you are using that is very important, how it can be classified? Of course, you have to know the in fluidization purpose whether this classification of the particles whether it is the smaller particles or finer particles or you can supports the particles that. So, 1973 geld art; he has given the standard a segregation or standard way of representation of the particle by classifying in different group and he actually categorized the particles based on the diameter and the relative density of the particles, the particles to represent that different groups of particles and segregate that in different groups based on their size.

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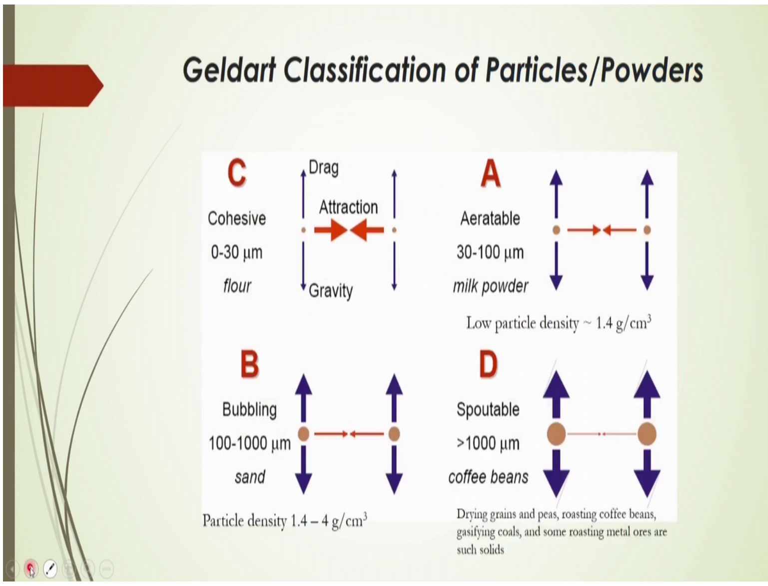

And he actually identified four regions in which the fluidization character can be distinctly defined. What are those four regions of the particle class? He has defined the four regions like C, A, B, D. What is this C means? cohesive groove; that means, here the solid particles a size will be ranged between 0 to 30; that means, up to 30 micrometer you can define this particle as a cohesiveness of particles, this is very fine particles and because of these fine particles this you know that van der Waals force or this attractive force will be more higher and because of which you will see that the cohesiveness nature will exist in this group.

So, that is why this is categorized as C group; C means, cohesive. A example like; flow particles whatever in market commercially available you see the particles are very fine it will be less than 30 micron in size, because this and also whenever you will add some water in the particles that the particles will you will see you very difficult to segregate from each other. So, that is why it is called more cohesiveness it in nature.

And here in this case this attraction between the particles will be very high. And another type it is called Aeratable, Aeratable means here in this case you will see if you allow some gas through this space of these particles you will see the gas will be escaping from it is space between the particles. So, this aeration possible by these particles in this case the size of the particles will be within the; a range of 30 to 100 micrometer, so like milk powder you can easily flow you can easily fluidize this milk powder by just by variation.

So this is called, why it is called Aeratable? In this case a size will be within the range of 30 to 100 micrometer and generally low particle density are being categorized in this case to 1.5 gram per cc, another one is bubbling I think I have shown that that bubbling fluidization, so bubbling fluidization occurs on the B type particle; this B type particle means the size range will be 100 to 1000 micrometer; like sand, if we are using sand particles sand particle within the range of 100 to 1000 micrometer you will see the formation of bubble inside the bed.

So, in this case the attraction force will be not as much higher than the C type particles or B type particles, another type it is called D type in this case the particle size will be very a coastal; that means, the size range will be is greater than 1000 micrometer like coffee beans the size is greater than 1000 micrometer. So, in this case the spout able nature of the a fluidization occurs, you will see the gas will be making a channel through the space of the particles and also there will be certain thrust of the cash particles and also movement of the solid particles downward and upward and in a certain fashion the gas should be moving up. So, in that case the; this is represented by this spout able type of diameter or spout able type of type of particles like coffee beans, the drying grains or peace roasting of coffee beans you will see the gasifying coals also this type of particles are being used for that operation and it is feasible.

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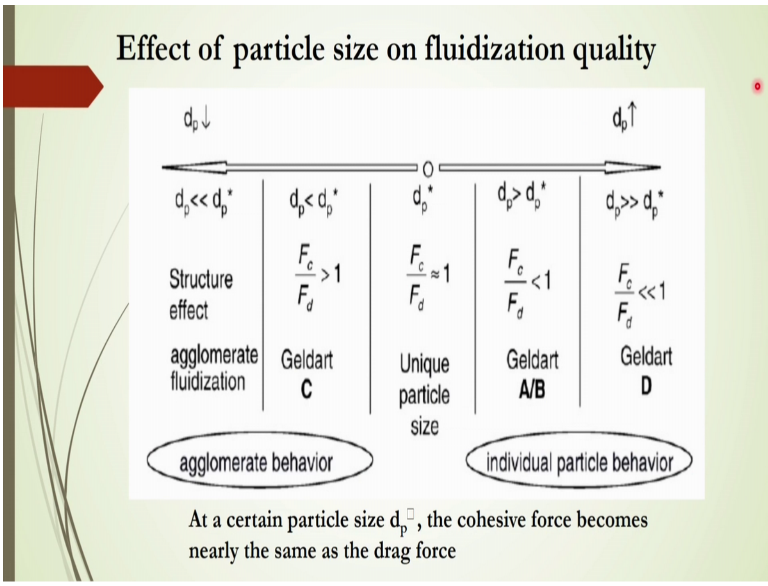
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Effect of particles and the fluidization quality, how this a particle size based on these forces will affect the fluidization quality. And if you see this if you decrease the particle size and if you increase the particle size in this case the agglomeration behavior will increase because of this change of the particles if you decrease the particle size agglomeration will decrease whereas, if you increase the particle size this individual particle behavior will increase.

So, points so this is actually basically that how this force will be applied in the fluidization quality and also the size it is matters and what should be the difference as well, so these are the things basic things that you have to know what will be the particle size, how it will behave on the fluidization. So, next class we will discuss the geld art different classification of the particles of powders and others this size of these particles or classify the size of these particles how it will change the flow pattern of the fluidization.

Thank you.