INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
NPTEL
NPTEL ONLINE CERTIFICATION COURSE
Mechanical Operations

Lecture-02
Characterization of a single particle-1

With
Dr. Shabina Khanam
Department of Chemical Engineering
Indian Institute of Technology Roorkee

I welcome you all in the second lecture of the course mechanical operation. And this lecture consist the characterization of single particle.

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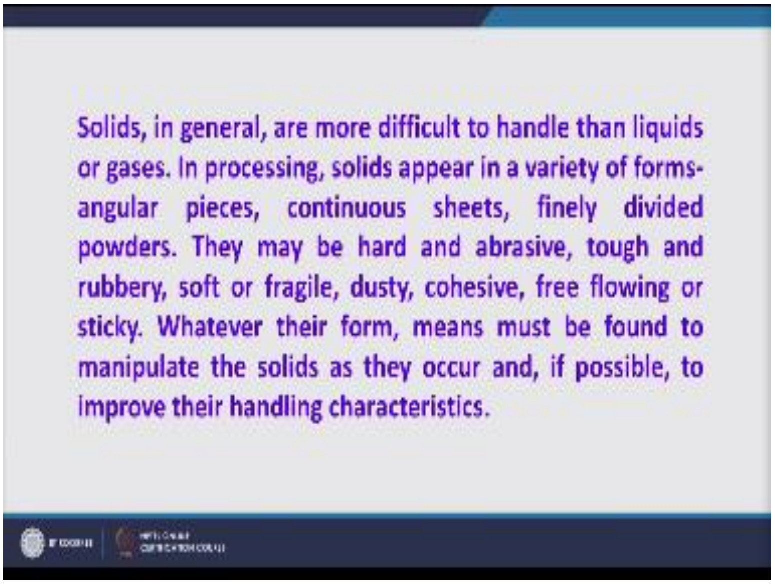

As you understand that mechanical operation deals with the solid, so solid in general, are more difficult to handle than liquid or gases. In processing solids appear in a variety of forms such as angular pieces, continuous sheets, finely divided powders. They may be hard and abrasive, tough and rubbery, soft or fragile, dusty, cohesive, free flowing or sticky. So depending upon the nature of the solid.

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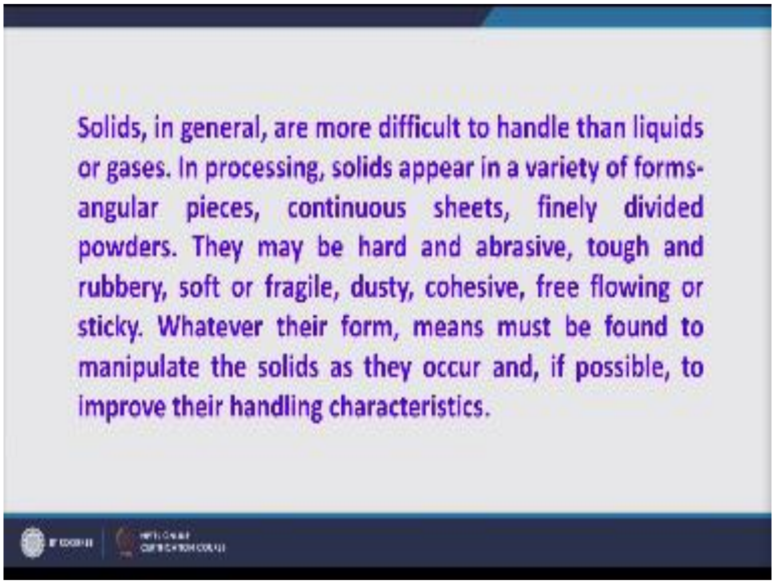

We have to handle all these solid differently. So whatever they are form like whatever their shape like it is angular piece, continuous sheet or whatever their nature means must be provided, means must be found to manipulate the solid as they occur. And if possible to improve their handling characteristic.

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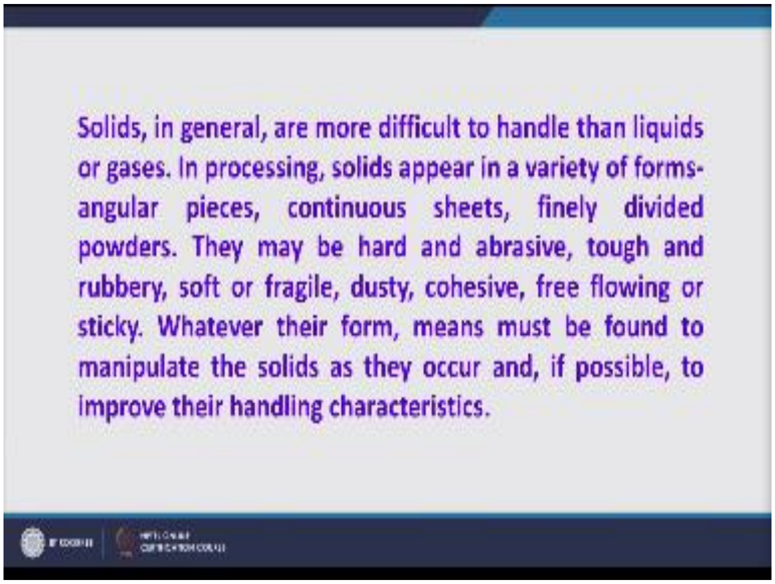

So we have to think about handling and processing of different type of solids according to their behavior, according to their nature, as well as their shape. So when I consider about their behavior, their shape I'm basically speaking about the characterization. So now the characterization of a particle we are going to define. Now what is characterization if I consider the characterization of a human being how we can characterize our self.

I can characterize myself by my height, I can characterize myself by my weight or sometime we can characterize our self by the skin color. So similarly characterization of some single particle or characterization of a particle has two different part.

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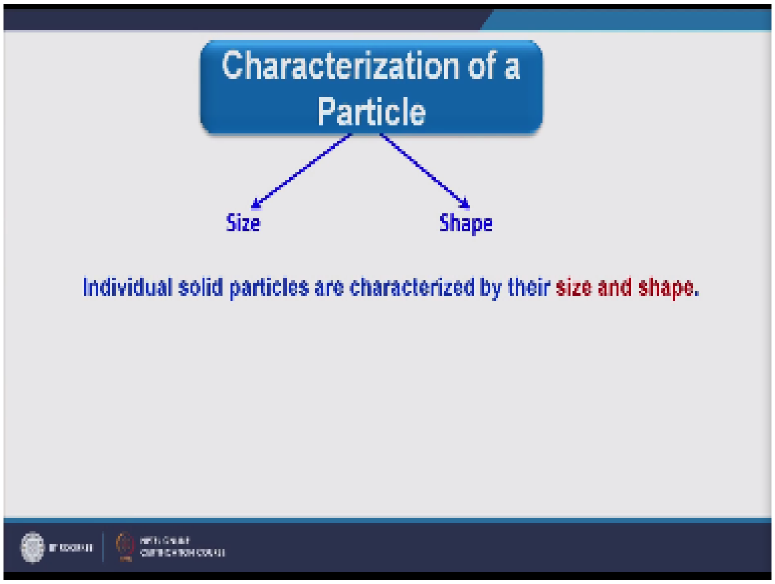

First is we can characterize a particle by its size, and second we can characterize the particle by its shape. So individual solid particles are characterized by their size and shape along with size and shape there is another parameter which we call density which consider as a characteristic parameter of a particle.

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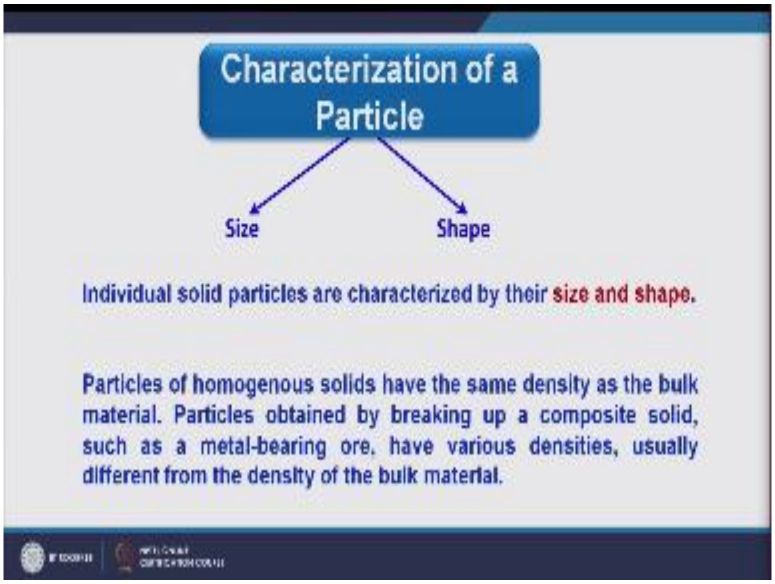

So particles of homogeneous solid have same density as the bulk particle. If I consider a small section of a particle a small section of a matter from a bulk it will have the same density as the bulk itself. However when the particles obtained by breaking up a composite solid, such as metal-bearing ore, have various densities, usually different from the density of the bulk material. And that is quite obvious like if we are taking breaking a rock or breaking a composite solid and if we break it in different number of particle.

If I consider one particle it may have one composition more in comparison to other composition. In the similar line the second particle of the same rock has second composition more in comparison to the first one. So according to the composition densities may vary.

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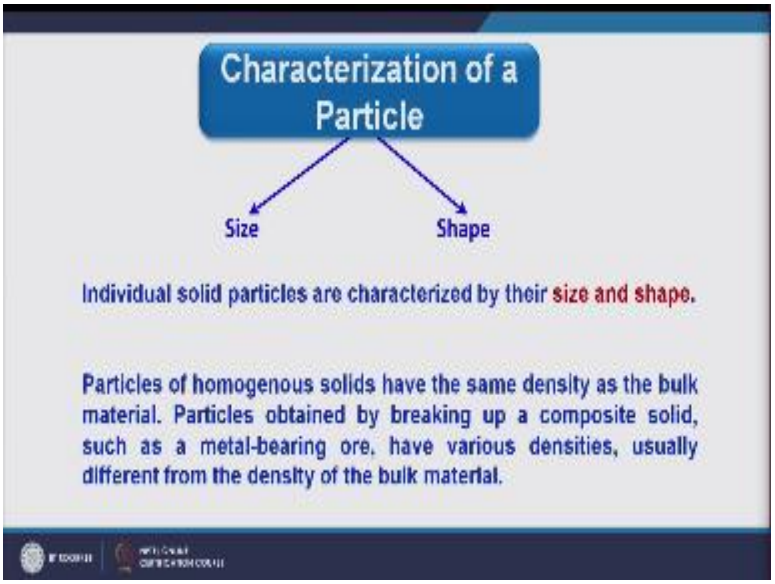

Therefore density of a particle play important role along with size and shape. Now before starting the size and shape of a particle, let me define what is a single particle.

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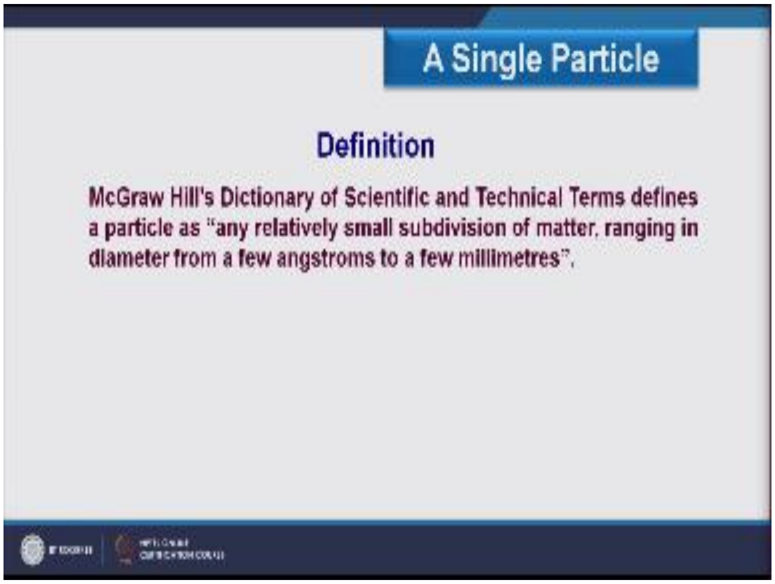

What we call a particle and how we can define this. So McGraw Hill's Dictionary of scientific and technical terms defines a particle as "any relatively small subdivision of matter, ranging in diameter from few angstroms to a few millimeters". So you can understand it is a small division, a small part of the complete matter and it may have different diameters.

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Particles that one wishes to measure for size may be composed of organic and inorganic molecules; they may be molecularly homogeneous or inhomogeneous; they may be in solid or liquid state; they may be of any shape; and may be suspended in various media. So according to their nature; according to their shape; according to their composition the measuring technique differs.

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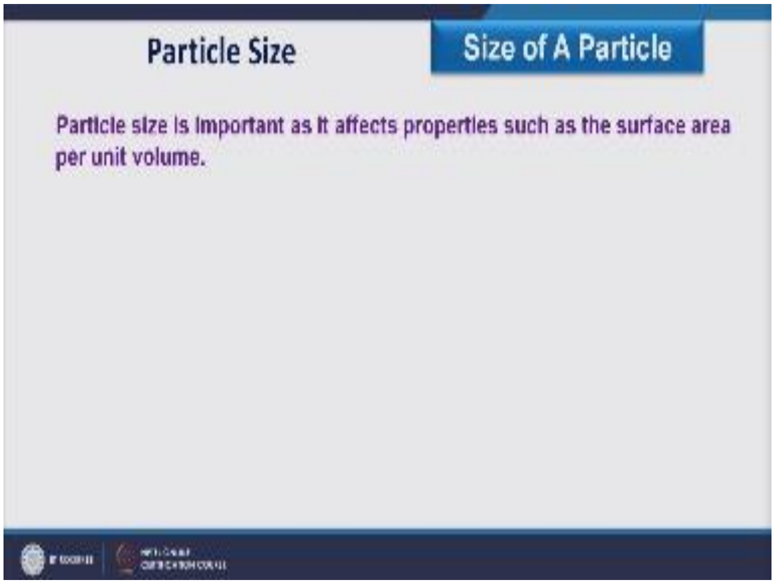

So when we measure the particle size the question comes, why I am measuring the particle size. The particle size is important as it affects properties such as surface area per unit volume, and if you remember the last lecture we have discussed that particle size affects the property which are directly related with the success and failure of the product. So therefore it is important to measure the particle size.

Now if I consider the particle in a mixture each particle has three dimensional, it has three dimension like length, breadth, and height. And if I define, if I want to measure the particle size its length, breadth, and height should be measured to describe it completely.

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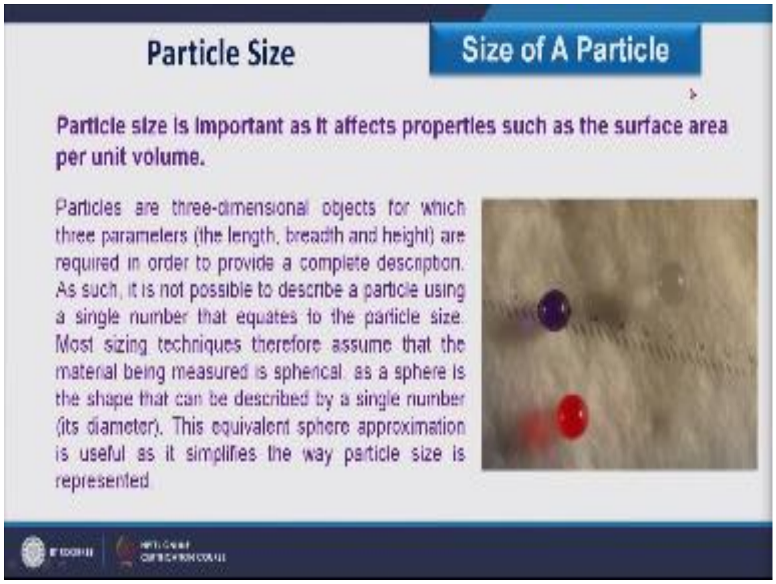

I am showing one picture in this picture if you see though this picture is 2D image here you are saying some of the spherical balls and these spherical balls are basically 3D image 3D object not the 3D image, it is the 3D object. So similarly each particle is having three different dimension, though it has spherical has only one but usually particle has three different dimensions. And if we are going to measure all these three dimension of all the particle it will be very difficult and practically impossible.

As such it is not possible to describe a particle using a single number that equates to the particle size. Most sizing techniques therefore assume that the particle being measured is spherical. As a spherical is the shape that can be described by single number that is its diameter. Therefore instead of measuring three different dimension of a single particle in a mixture we can simply equate them to the sphere and then we can measure the size of that sphere.

So this equivalent sphere approximation is useful as it simplifies the way particle size is represented.

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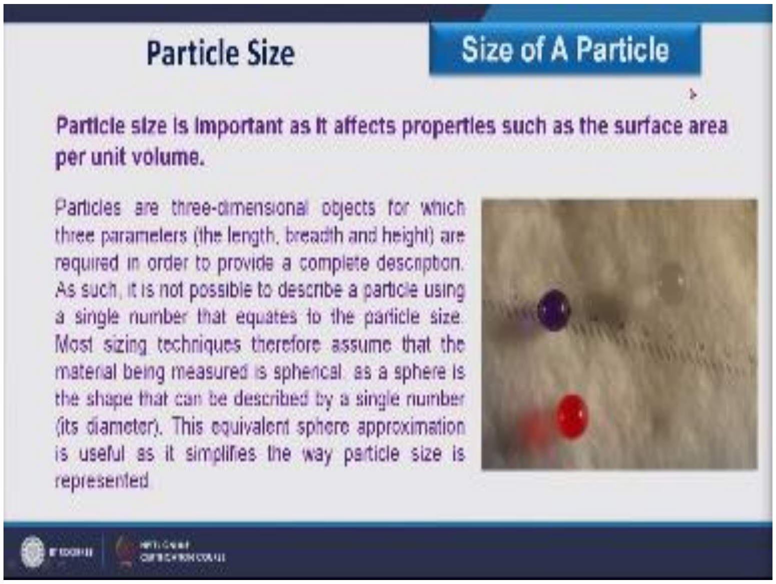

Now if all fine particles I am considering as a sphere their size would be defined exactly by their diameter or radius.

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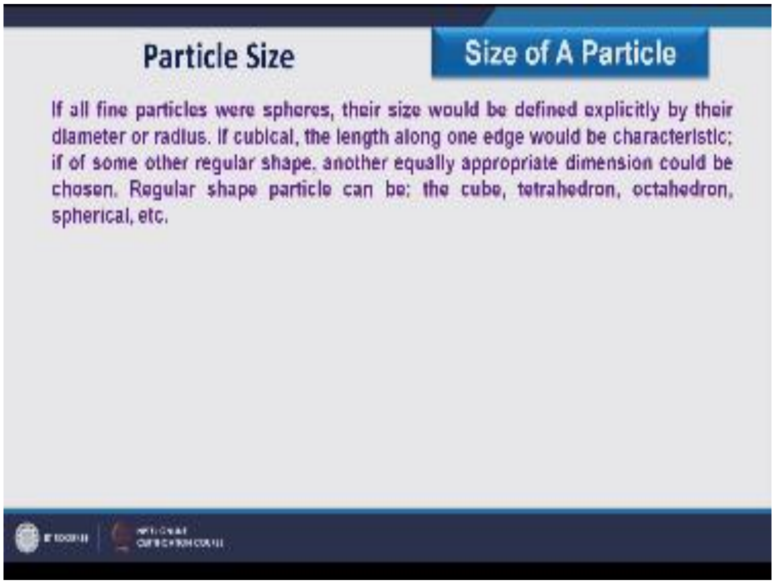

Because all particles are of spherical shape if the particle are of cubical shape the length along one edge would be the characteristic, if of some other regular shape another equally appropriate dimension could be chosen. Now if you see this we can have only single parameter to define the size of particle when the particle shape is regular.

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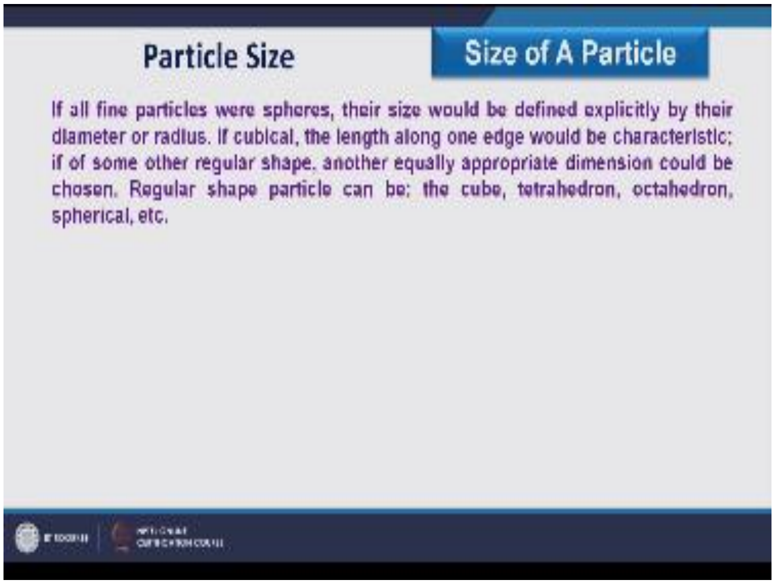

When I say regular shape the cube tetrahedron, octahedron, spherical etc come under this.

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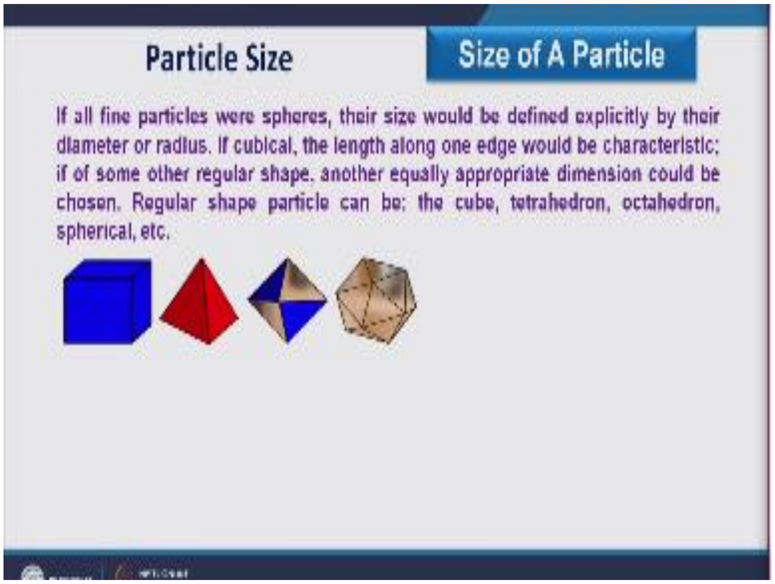

So all these shape which I am showing all these are having regular shapes. However in actual scenario the particle are quite irregular in geometry. And if we define all three dimension of this it will be very time consuming. So every collection of particle contains particles of many different sizes commonly referred to as particle size distribution.

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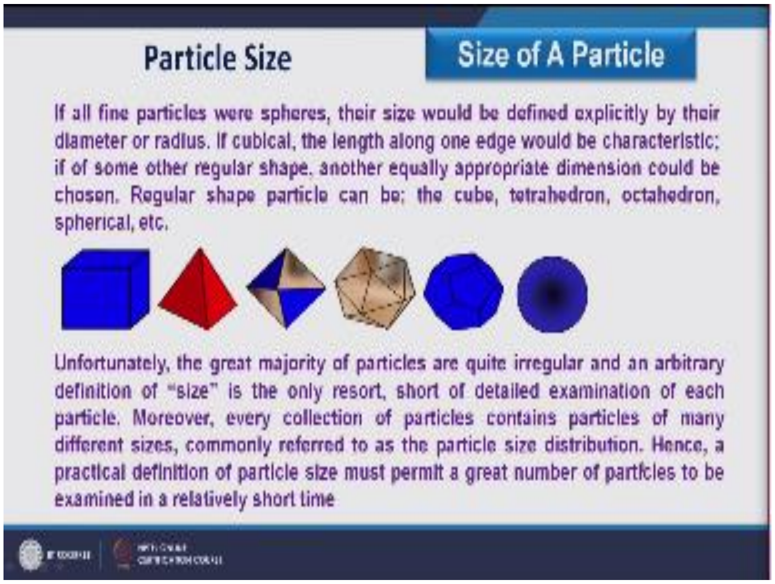

So if I consider the single particle and if I consider the bunch of particle, or the mixture of particles, in mixture of particle we usually define distribution like some amount of some mass fraction of total mass having a particular size, another mass fraction of total mass is having another size. So accordingly we define the particle size distribution.

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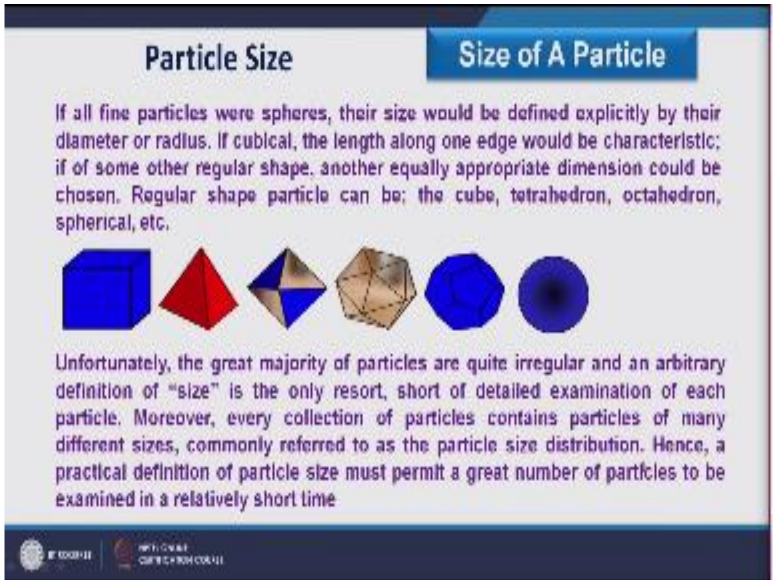

And in that mixture when we define particle in terms of all three dimensions that is practically impossible or it is very time consuming. Hence a practical definition of particle size must permit a great number of particles to be examined in a relatively short time.

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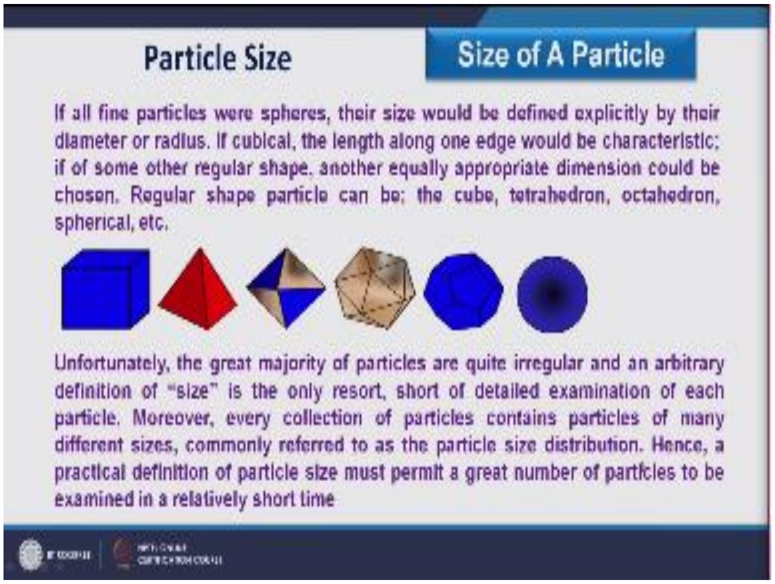

Therefore to define a particle using a single dimension basically it determine the particle in very short time.

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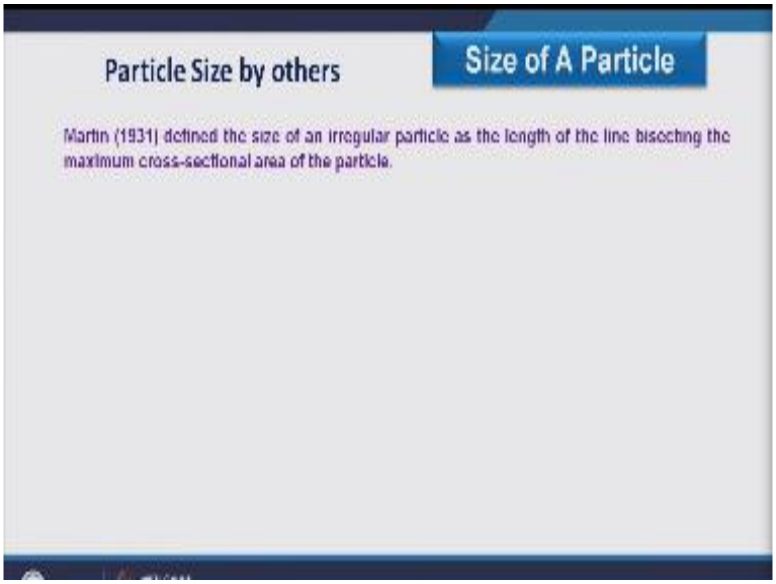

Therefore to define the size of particle using single dimension a few researchers have shown some has proposed some definition like Martin 1931 define the size of an irregular particle as the length of line bisecting the maximum cross-sectional area of the particle.

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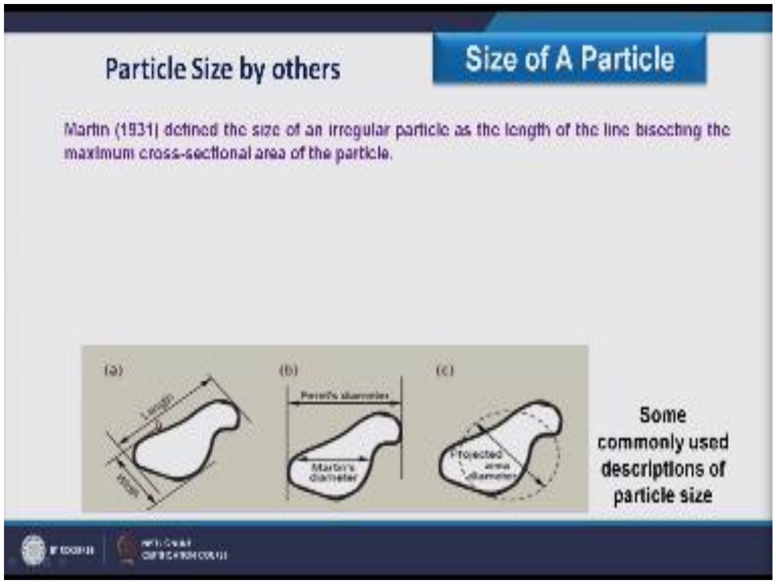

Now for example if I am having this particle and this is the width of particle, this is the length of particle it is quite irregular in shape. So first of all we have to place the particle in such a manner so that its maximum cross-sectional area should be the projected area.

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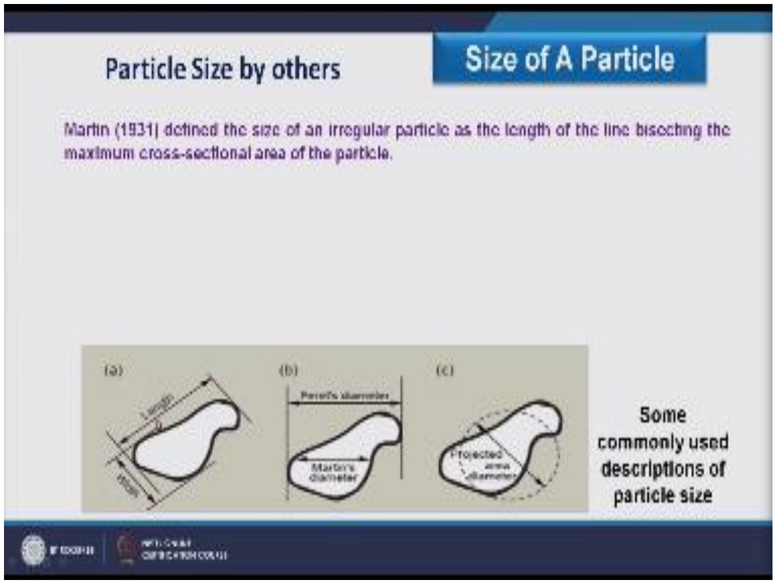

Once I am having this then Martins diameter are that length which divide this complete cross-sectional area into two equal parts there that is why it is telling as line bisecting the maximum cross-sectional area of the particle. So this is the Martins diameter.

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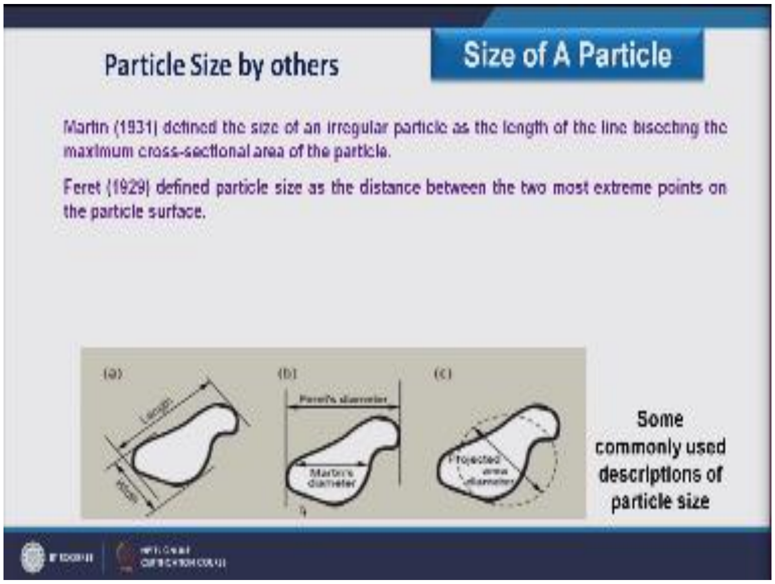

Another diameter we have is the Ferets diameter who has defined like if particle is projected to its maximum cross-sectional area the length between the longest edges of the particle is basically called the Ferets diameter. So if I consider martins diameter and ferrets diameter they both have been defined based on the maximum cross-sectional area to be the projected area. And if I consider this particular definition what is the limitation of it, is it the exact definition that we want.

Now if I consider martins and Ferets diameter of this particular particle, for example, the, I am having two particle one is having same cross-sectional area as it is another is having also same cross-sectional area. Now particle one is having that width of this is as like 1mm another particle is having 2mm. So whatever would be the width of it irrespective of this their Ferets and martins diameter would be equal I hope you are getting that. So that is the basic limitation of Ferets and Martin diameter.

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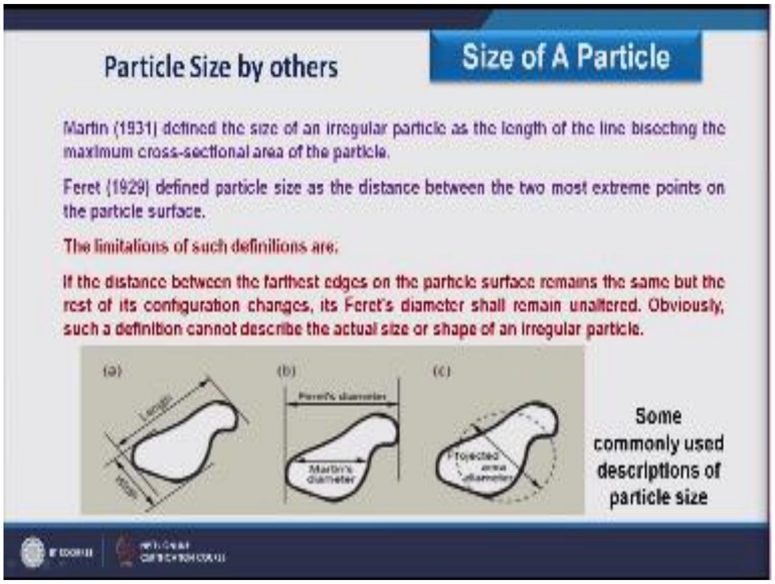

The limitations of such definition are if the distance between the farthest edges on the particle surface remains the same but the rest of its configuration changes the Ferets diameter and or Martins diameter shall remain unaltered, that's why I am telling that if in this side one particle is having 1mm or another particle is having 2mm both will have same Ferets and Martin diameter. So obviously such a definition cannot describe the actual size or shape of irregular particle, so that is the limitation of this.

So the simplest shape of particle is the sphere. If we consider the sphere it is basically the simplest shape why I am calling it simplest because it has only one parameter to be measured. Another point is when we have different orientation of this sphere it does not affect the size of the particle. So the simplest shape of particle is the sphere because of its symmetry any question of orientation does not have to be considered.

Since the particle looks exactly the same from whatever direction it is viewed and behaves in the same manner in the field.

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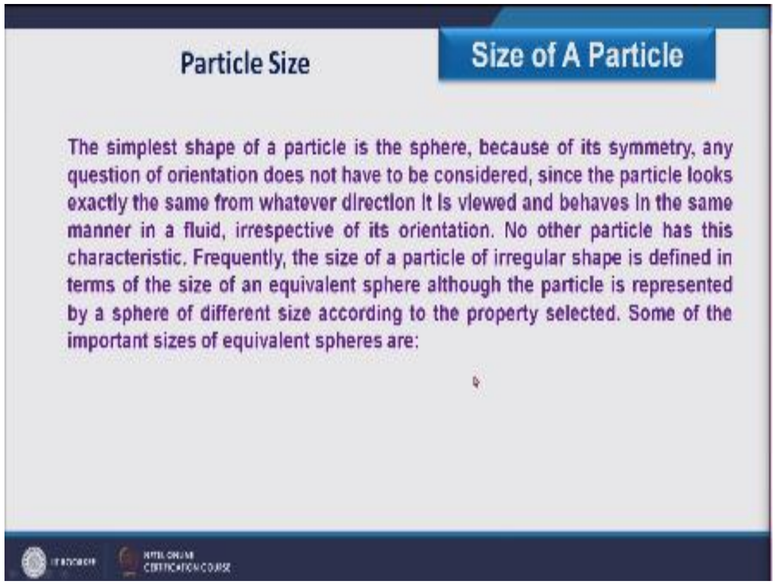

Therefore we try to define all irregular particle with sphere. Now how we can do this the size of a particle of irregular shape is defined in terms of size of equivalent sphere although the particle is represented by a sphere of different size according to the property selected. Now what is the meaning of the property selected. The property means for what purpose I want to measure the particle size. So some of these important sizes of equivalent spheres are.

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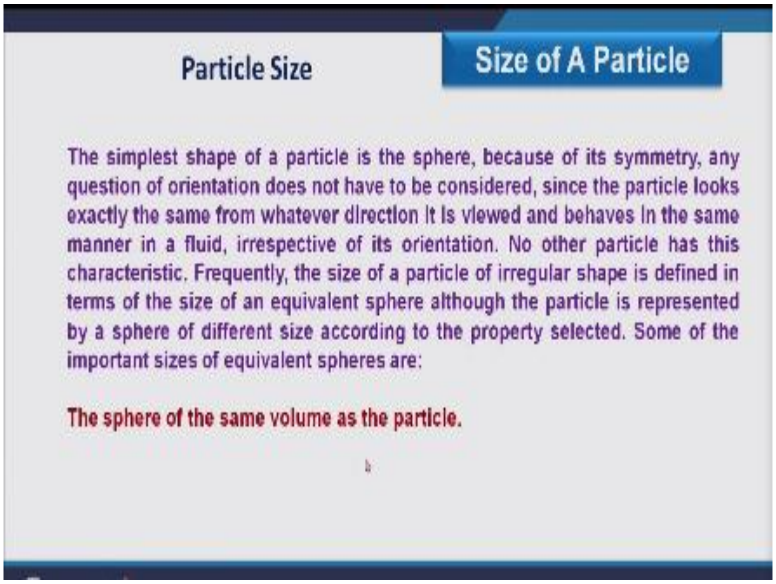

The first one is a sphere of same volume as the particle. So in this case volume would be that property I am saying that the property selected so in this particular case volume is that property.

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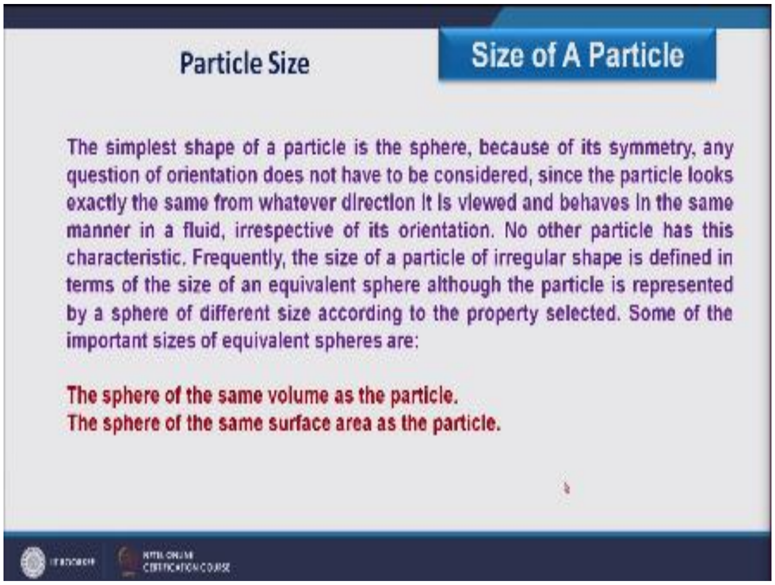

Another point we have the sphere of same surface area as the particle. So property is the surface area further the sphere of same surface area per unit volume as the particle, so surface area per unit volume is the property.

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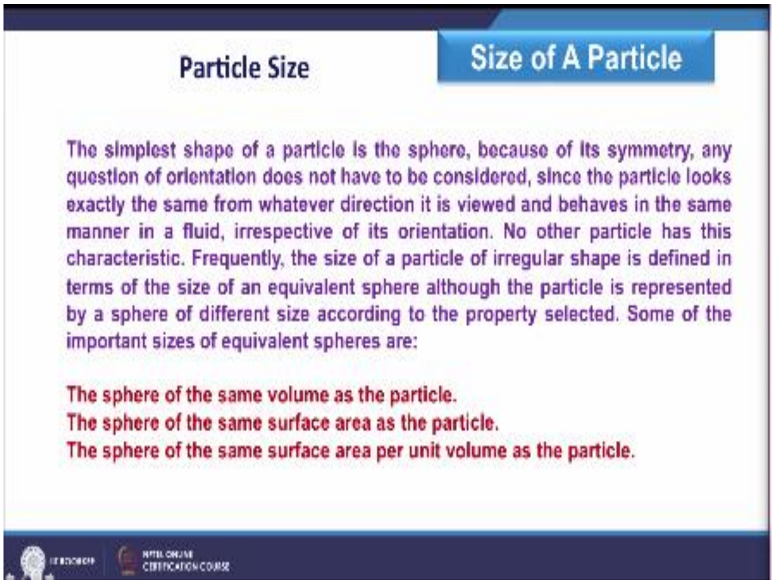

So according to the property we can equate the irregular shape of a particle to the sphere. So let me define the particle diameter.

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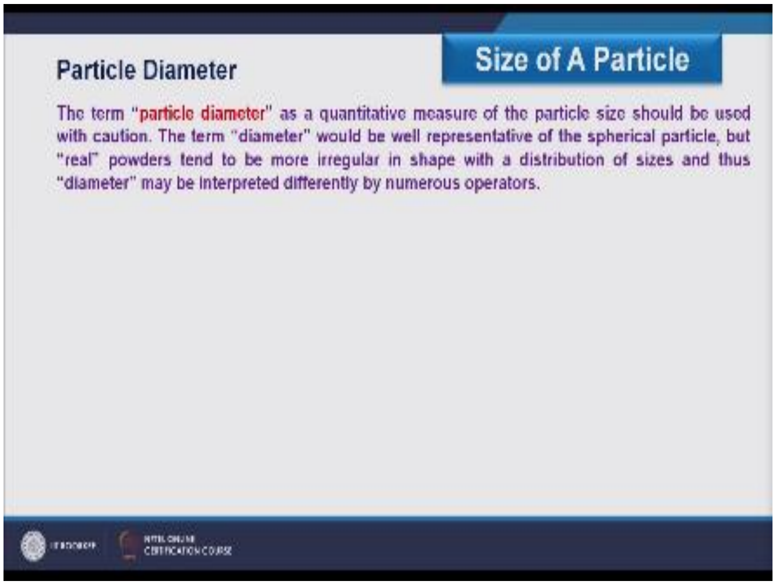

The term particle diameter as a quantitative measure of particle size should be used with caution. The term diameter would be well representative of a spherical particle, but real powder tend to be more irregular in shape with the distribution of sizes and thus diameter may be interpreted differently by numerous operators. So according to the property we can define the diameter of a particle while equating this to the sphere.

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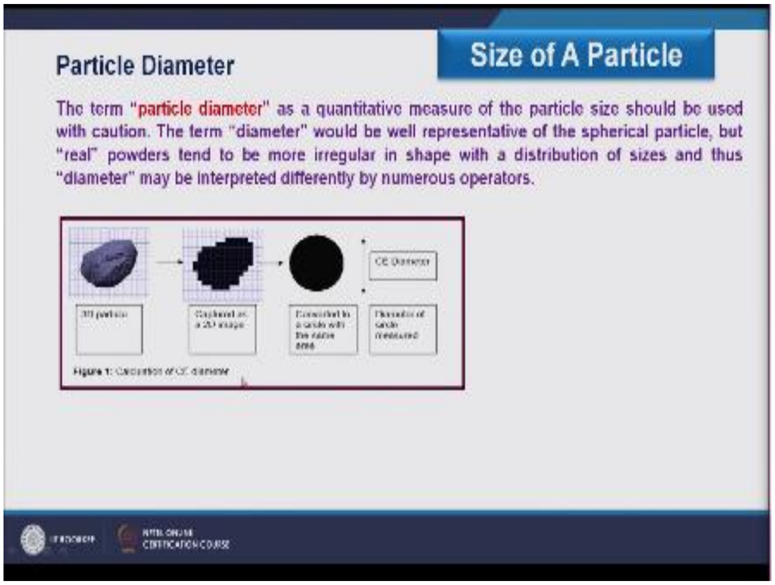

Now here I am defining one parameter which we call the CE diameter that is circle equivalent diameter. To define this diameter here I am having this 3D particle which we have shown in 2D image of this. Now if I consider this particular size or particular image of a particle, how I can calculate the surface area of this while counting these cells we can calculate the surface area of the particle.

Now we can equate this to the circle, circle is basically the 2D object or 2D image. Now if I want to equate this circle with this image we can equate in terms of equal surface area, so convert it to the circle with the same area and we can calculate a diameter of this very easily, so that we call at circle equivalent diameter.

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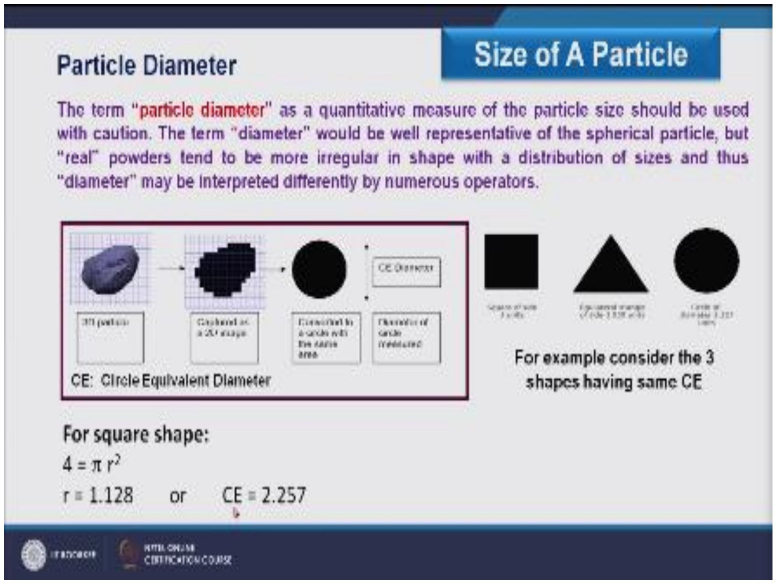

Now here I am having few different shape which are having equal circle diameter. For example, if I consider this as square, this as triangle, and this as circle both are having circle equivalent diameter equal to2.257. Now if I consider the example of this square if it is, one side is two unit so put total surface area of this is 4 which is equivalent to the πr^2 that is surface area of the circle we can calculate a radius from this and then we can calculate the circle equivalent diameter.

So if we want to define the particle in terms of circle that will not give me that exact image because it has 3D dimension also.

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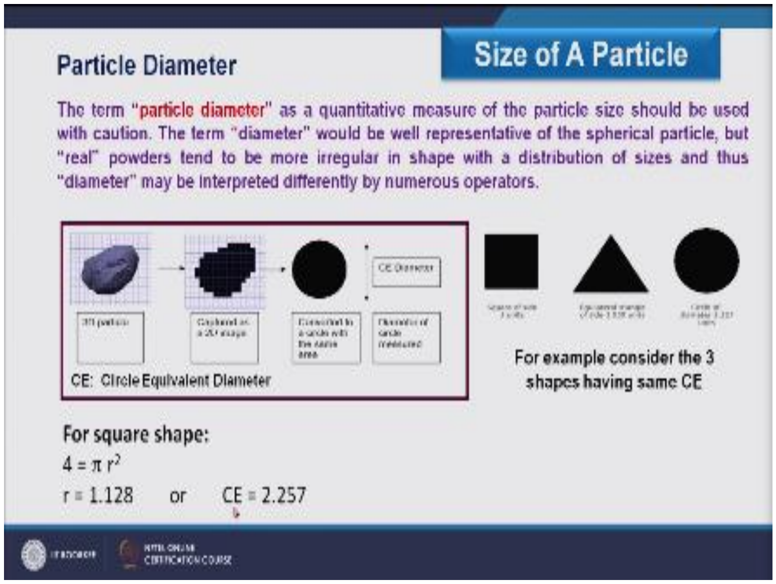

So we can define the particle in terms of a sphere instead of circle.

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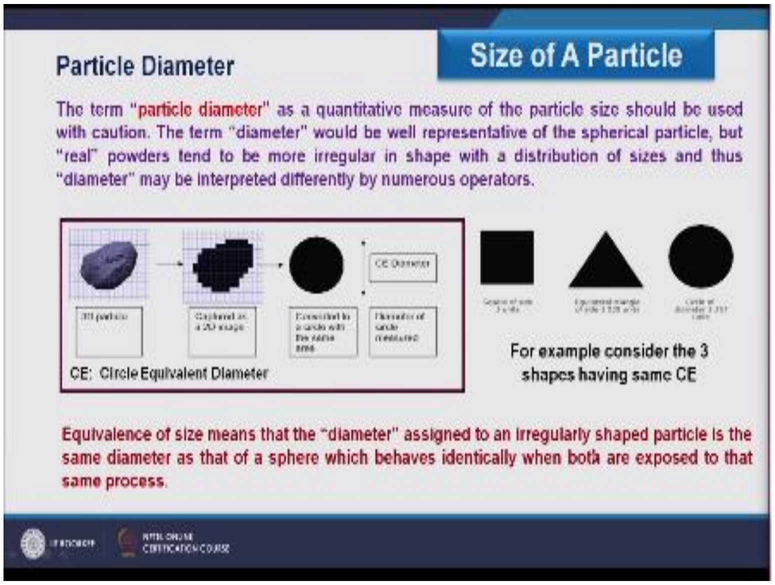

So equivalence of size means that the diameter assigned to an irregularly shaped particle is the same diameter as that of a sphere which behaves identically when both are exposed to the same process. So that is basically the meaning of equivalence that it is, it should not affect the process while considering irregular particle or spherical particle, the process in which it is involved it should not be affected.

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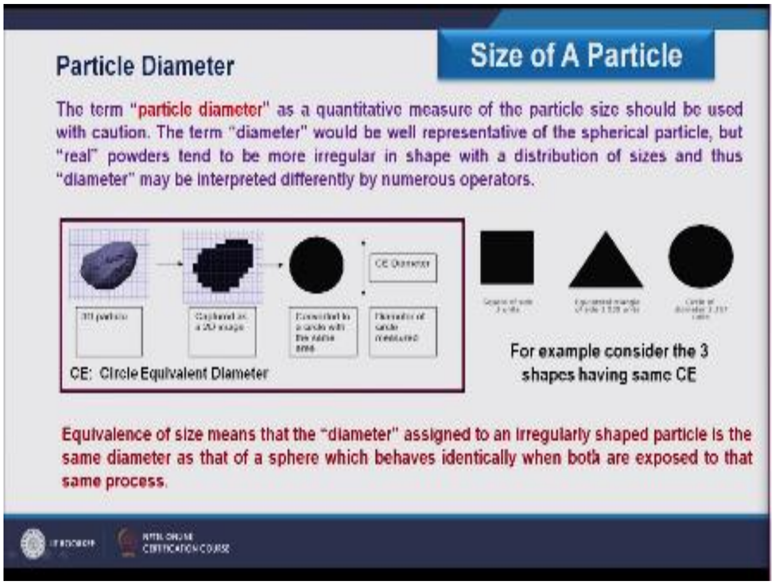

Therefore we are trying to equivalent the particle irregular particle to the sphere particle. So that their behavior in the process should be similar, so here I am having definition of diameters.

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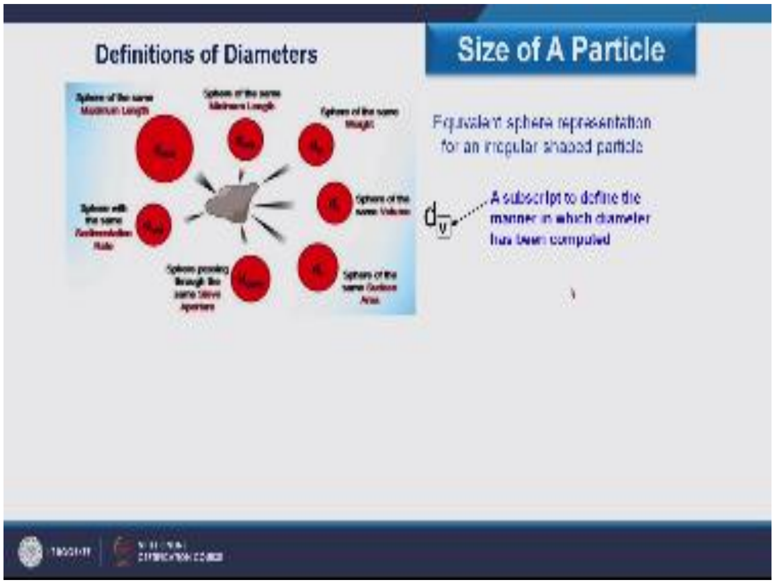

If I am considering this is basically the irregular particle and here I am having different diameters which we have defined based on different property. So these are basically equivalent is sphere representation of an irregular shape particle. If I consider this particular example here I am having this d_v that is sphere of same volume. So its diameter would be, we can say as dv. Now everywhere you see it is represented as d and subscript with a equivalent property, like here I am having d_v where v is basically a subscript to define the manner in which diameter has been computed.

So you can see there is only one particle and how many ways we can define the particle diameter.

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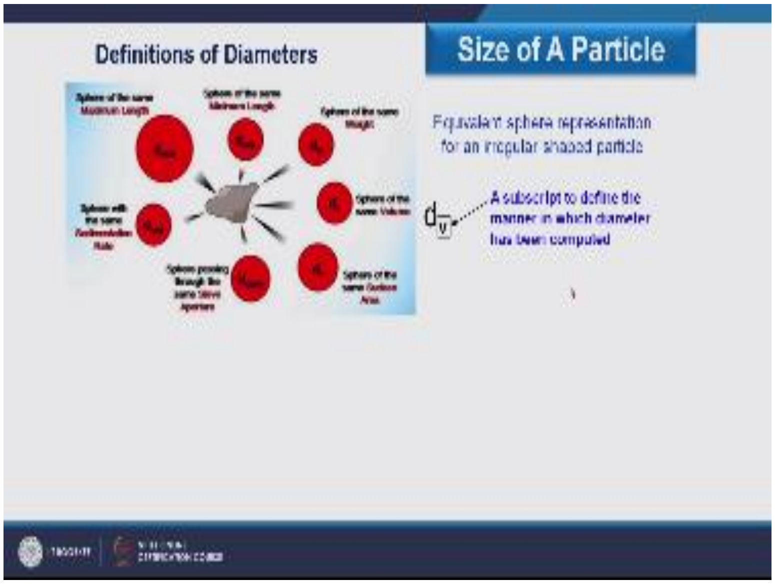

So it particularly depend on for what purpose we are using, what property we are using to equate the particle with the sphere. So here I am having some of the definition like if I consider surface diameter.

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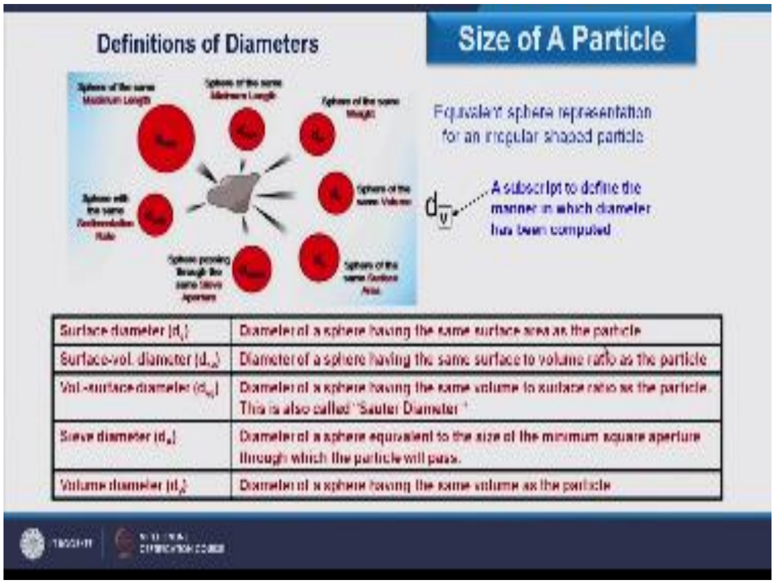

If I define surface diameter which is denoted as d_s that is the diameter of a sphere having same surface area as the particle. Second we have surface volume diameter that is d_{sv} diameter of a sphere having same surface to volume ratio as the particle, volume surface diameter that d_{vs} it is slightly different than this. Diameter of sphere having same volume to surface ratio as the particle and thus is also called sorter diameter.

Another definition we are having is the sieve diameter d_a that is diameter of a sphere equivalent to the size of minimum square aperture through which the particle will pass. Now what is this square aperture that I will speak in fourth lecture. Now another definition we have the volume diameter that diameter of a sphere having same volume as the particle.

Along with this you can see here I am having different definitions also, like if we consider this particular definition it is a sphere of same weight a sphere that d_w it is basically the diameter of a sphere having same weight as that of particle. And similarly here I am having a sphere of same minimum length, here we have a sphere of same maximum length. A sphere with the same sedimentation rate here we have defined the diameter accordingly.

So here you can understand that though we have irregular particle according to the purpose, according to the application we can define, we can equate this to our sphere in many ways. So till now we have seen different definitions of particle size, now here I am starting how to measure the particle size. So this is a fact that the way we measure a particle size is as important as the value of measured size.

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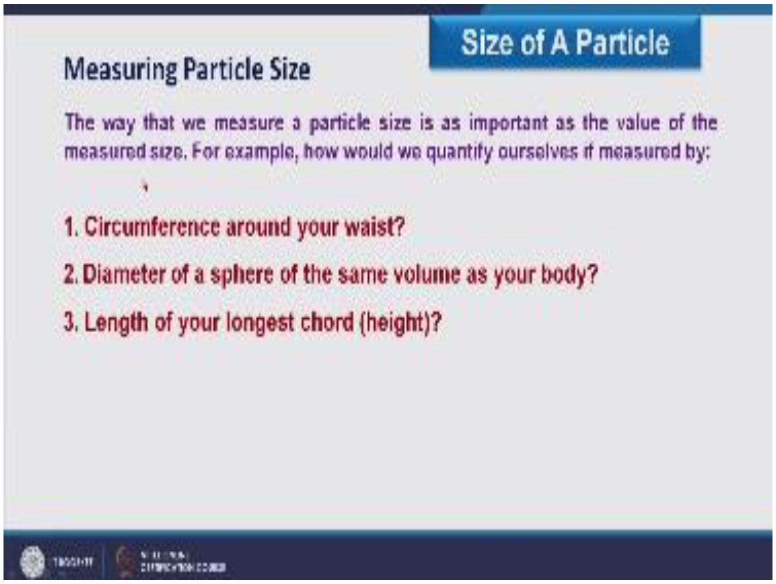

It means that the size which we have measured that is important and along with that it is also important that on which basis it is measured like what property we have selected to equate this to the sphere and then we have measured the diameter of this sphere in terms of irregular particle.

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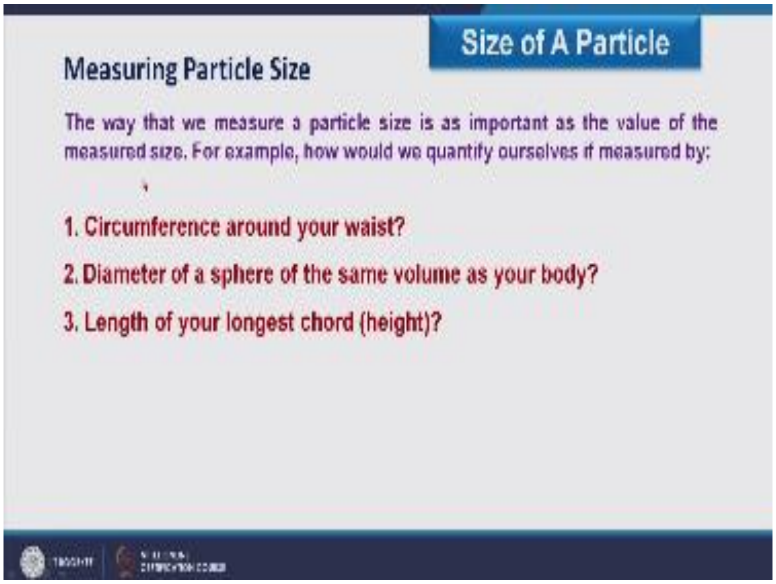

So here I am having another example like how would we quantify ourselves if measured by circumference around your waist, diameter of a sphere of same volume as your body, length of your longest chord. Now among this what way we are measuring ourselves is dependent on for what purpose we want to measure. For example, if I want to purchase the belt then definitely circumference would be the proper characteristic for this.

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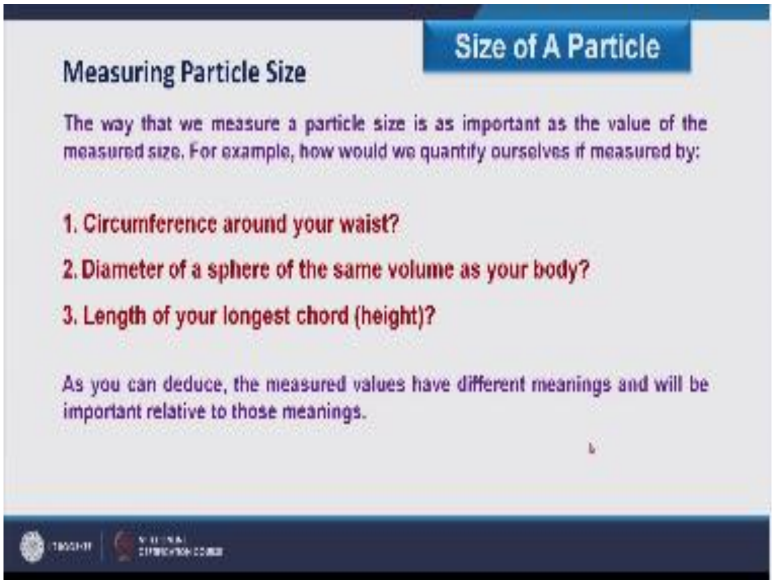

Therefore as you can deduce, the measured value had different meaning and will be important relative to those meanings.

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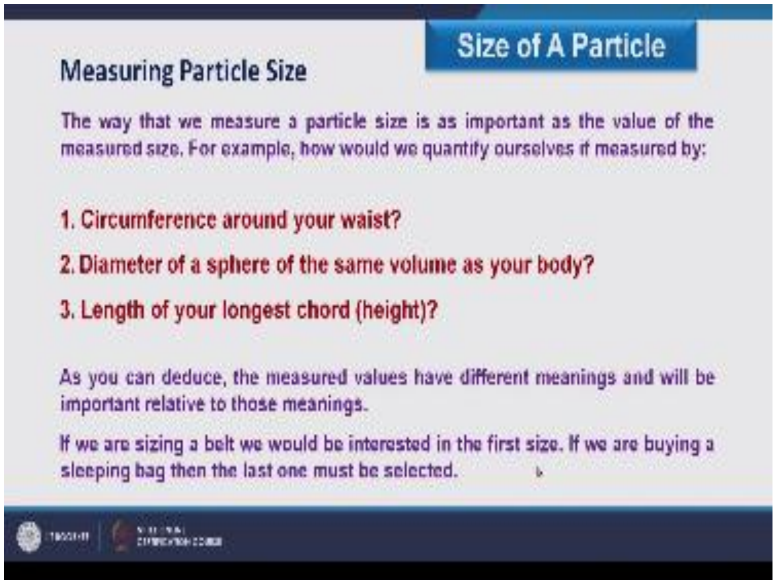

So here we have defined differently if we are sizing the belt we would be interested in first size that is to measure the circumference, if we are buying a sleeping bag for us the length of the longest chord that is height would be the measuring parameter. So you can understand measured size is important and on which basis for what purpose it is measured that is also important. So in the similar line we have some, we have related argument for the particle also.

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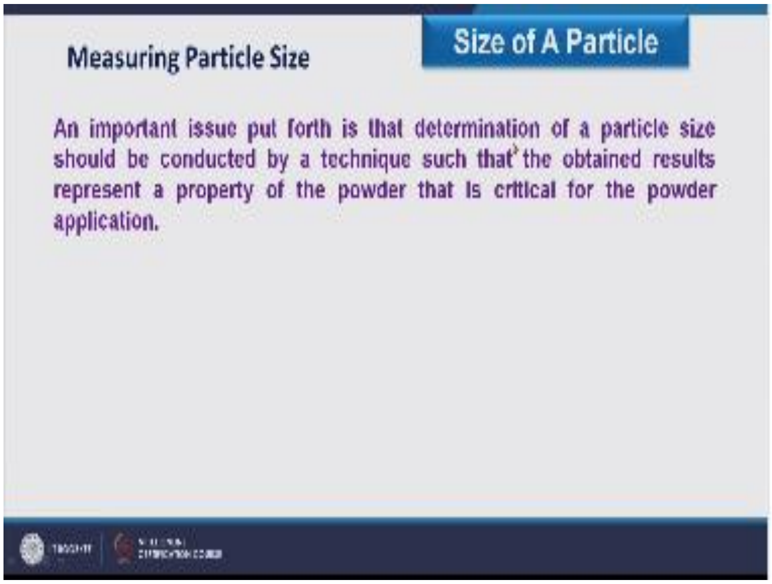

An important issue put forth is that determination of a particle size should be conducted by a technique such that the obtained results represent a property of the powder that is critical for the powder application. It means for what purpose, again I am speaking like where, when I want to equate a sphere to a particular property, it depends on for what application we want to do this.

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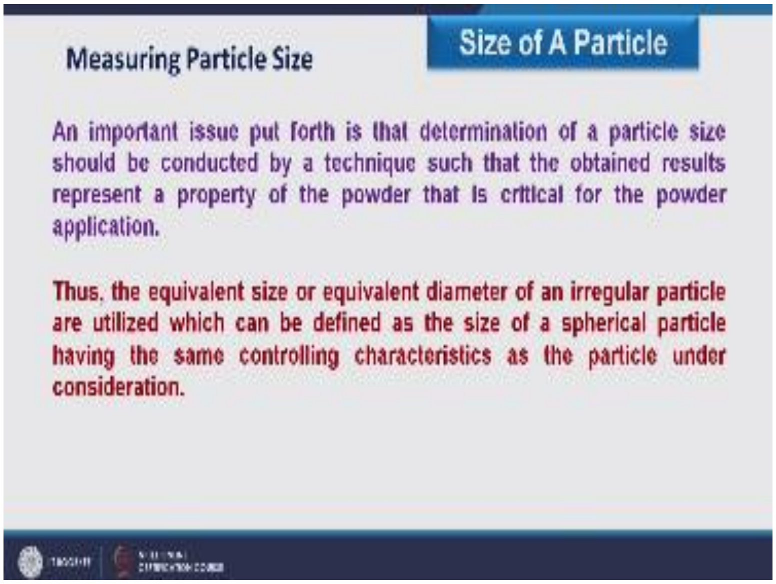

So thus the equivalent size or equivalent diameter of an irregular particle are utilized which can be defined as the size of a spherical particle having same controlling characteristic as the particle under consideration. So here you see we have defined another term that we call controlling characteristic which previously we have denoted this with the property like volume etc. Here we have that in terms of controlling characteristic.

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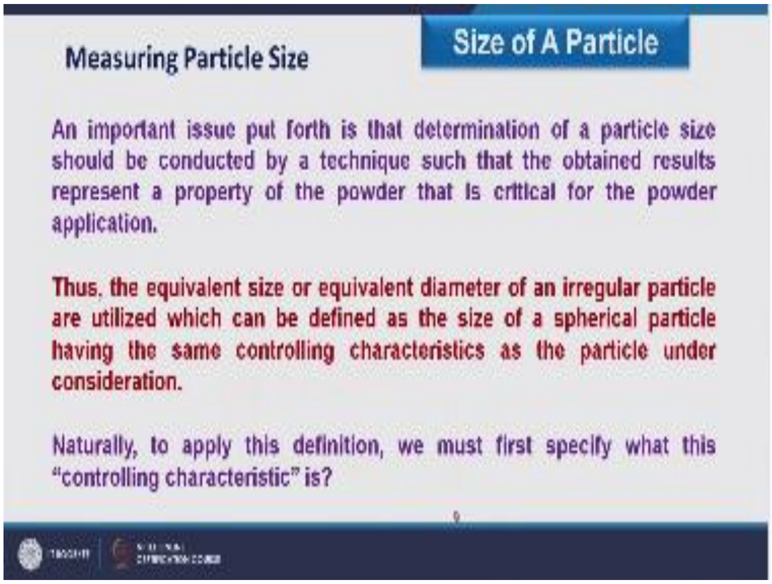

So naturally to apply this definition we must first specify what is controlling characteristic is. For example, if I consider the previous slide there we have the measurement of ourselves in different aspect, so that is according to the controlling characteristic. For example if I want to, if my purpose is to buy a sleeping bag then the height would be the controlling characteristic. So in the similar line for what purpose we are doing, we have to define the controlling characteristic first. And that controlling characteristic can be defined as.

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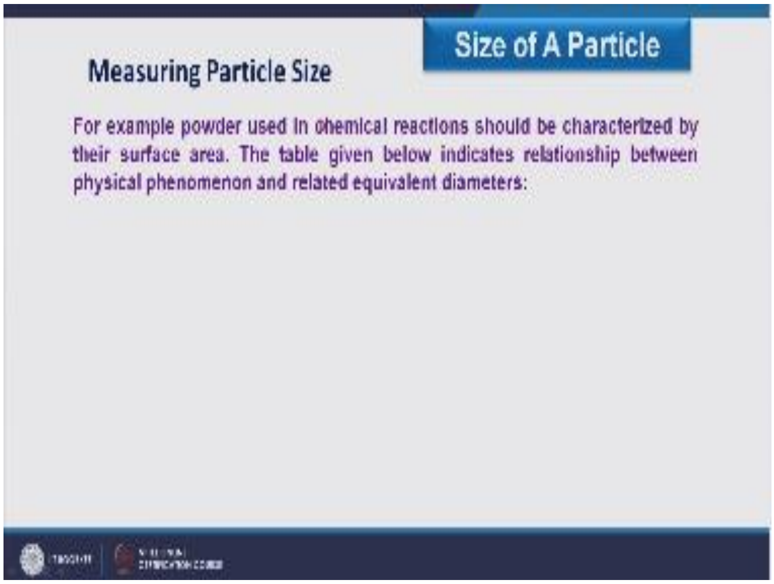

For example powder used in chemical reaction should be characterized by surface area. So in this case controlling characteristic would be surface area. The table given below indicates relationship between physical phenomena, and related equivalent diameters. Here I am having some processes in which particles are involved.

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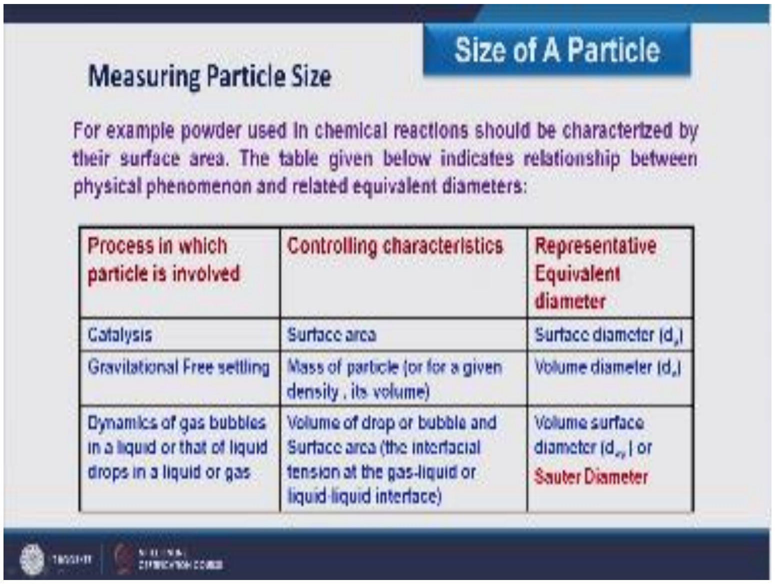

This is the controlling characteristic for this process and here I am having the equivalent diameter. For example if I consider catalyst, the surface of the catalyst is useful for any reaction to take place therefore the surface area for catalyst is a controlling characteristic and if I consider surface area, the surface diameter would be the equivalent diameter which can be defined as the diameter of a spherical particle having same surface area as the particle.

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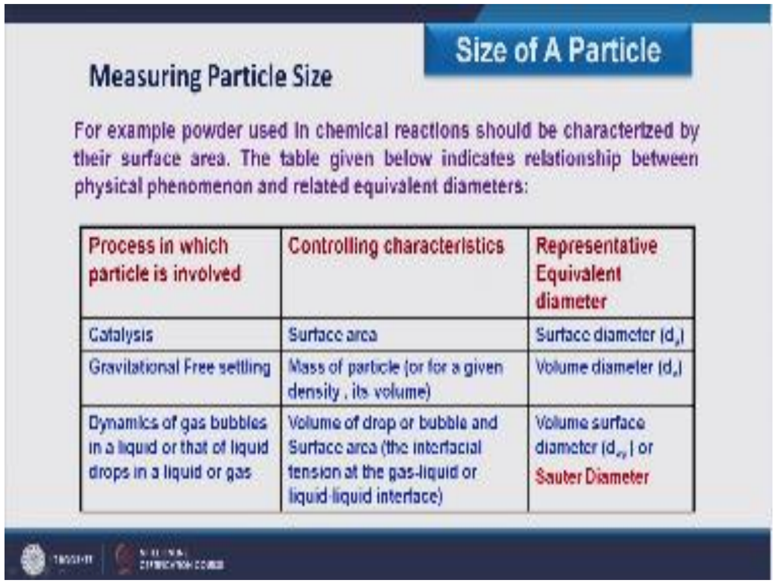

Process in which particle is involved	Controlling characteristics	Representative Equivalent diameter
Catalysis	Surface area	Surface diameter (d_s)
Gravitational Free settling	Mass of particle (or for a given density, its volume)	Volume diameter (d_v)
Dynamics of gas bubbles in a liquid or that of liquid drops in a liquid or gas	Volume of drop or bubble and Surface area (the interfacial tension at the gas-liquid or liquid-liquid interface)	Volume surface diameter (d_{sv}) or Sauter Diameter

Another process we have is the gravitational free settling in which mass of a particle is important mass of the particle is controlling characteristic or for a given density its volume. So in this case volume diameter we have defined as the equivalent diameter, third process is dynamics of gas bubbles in a liquid or that of liquid drops in a liquid or gases. So volume of drop or bubble and surface area why we have defined surface area?

The interfacial tension at gas liquid or liquid, liquid interface involves surface area as a characteristic. So if I am having the dynamics of gas bubble volume along with surface area would be the controlling characteristic. So in that case we have defined volume surface diameter as the equivalent diameter which we also call as sorter diameter.

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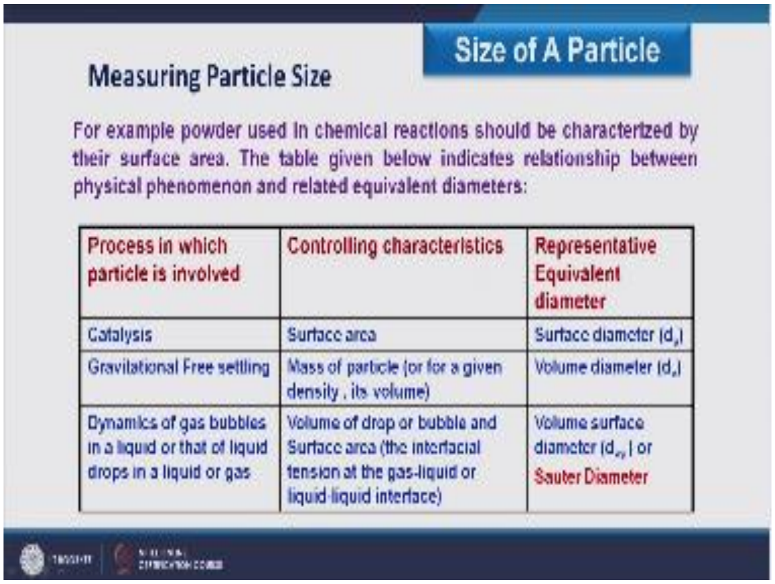

Now we are going to discuss all these processes and their equivalent diameter in detail in the subsequent slides.

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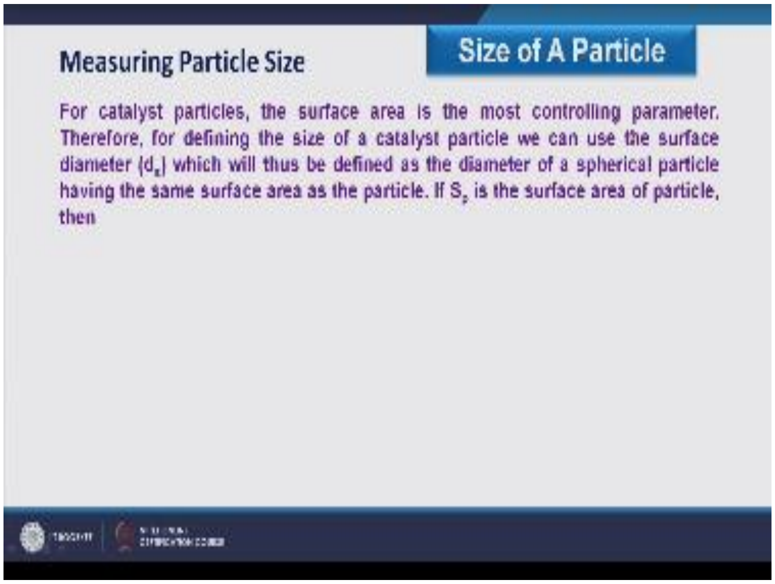

The first one is for catalyst particle, if we are considering the surface area is most controlling parameter. Therefore for defining the size of catalyst we can use the surface diameter which will thus be defined as the diameter of a spherical particle having same surface area as the particle.

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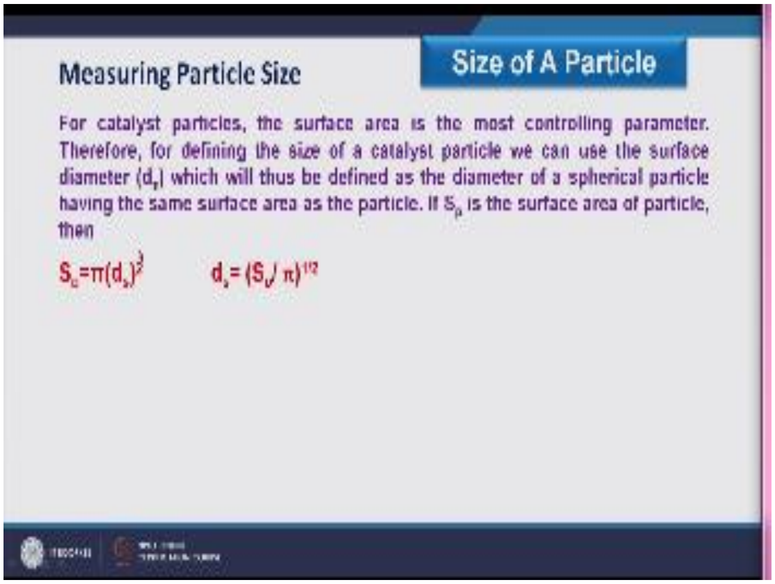

If S_p is the surface area of the particle then we can equate this to πd_s^2 where πd_s^2 is the surface area of a sphere. So when we equate this and when we calculate the diameter of this, this will be called surface diameter equivalent to the surface area of the particle.

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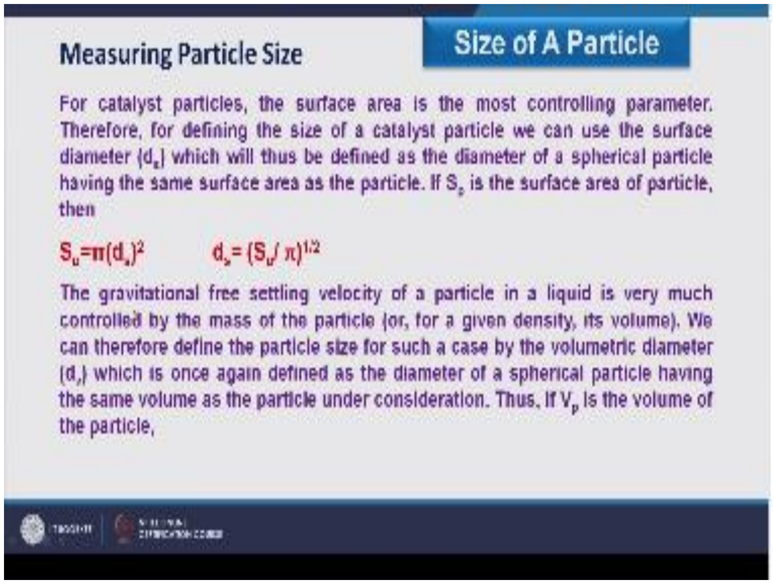

In the similar line another example is if gravitational free settling velocity that we also call terminal settling velocity of a particle in a liquid is very much controlled by the mass of particle. Now why I am saying this mass of the particle, if I consider the particle having more mass definitely it will fall through gravitation in short time in comparison to the lighter mass. So mass is the controlling characteristic in this or for a given density its volume.

So we can therefore define the particle size of such a case by volumetric diameter that is d_v which is once again defined as the diameter of a spherical particle having same volume as the particle under consideration. Therefore if V_p is the volume of particle then we can equate this $\pi d_v^3/6$ that would be nothing but the volume of a sphere we have equated this to the volume of particle and from this expression we can calculate d_v that is nothing but the volume diameter and it will be equal to $6V_p/\pi^{1/3}$.

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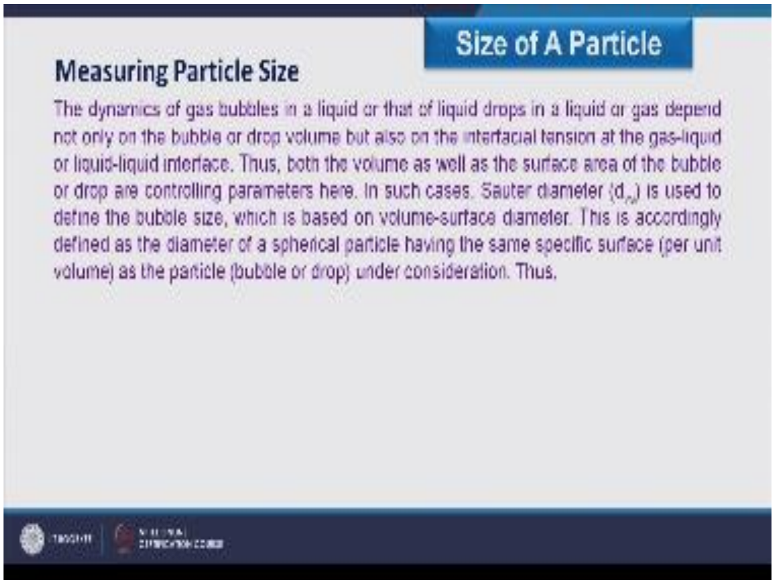

So accordingly we can define the equivalent diameter in different conditions, another condition I am having is the dynamics of gas bubbles in a liquid or that of liquid drops in a liquid or gas dependent not only on the bubble or drop volume but also on the interfacial tension at the gas liquid and liquid, liquid surface.

So if we are considering the dynamics of gas bubble the surface area along with the volume would be the characteristic. So in this case we have defined sorter diameter and we have denoted this with d_{vs} it is defined as the bubble size which is based on volume surface diameter.

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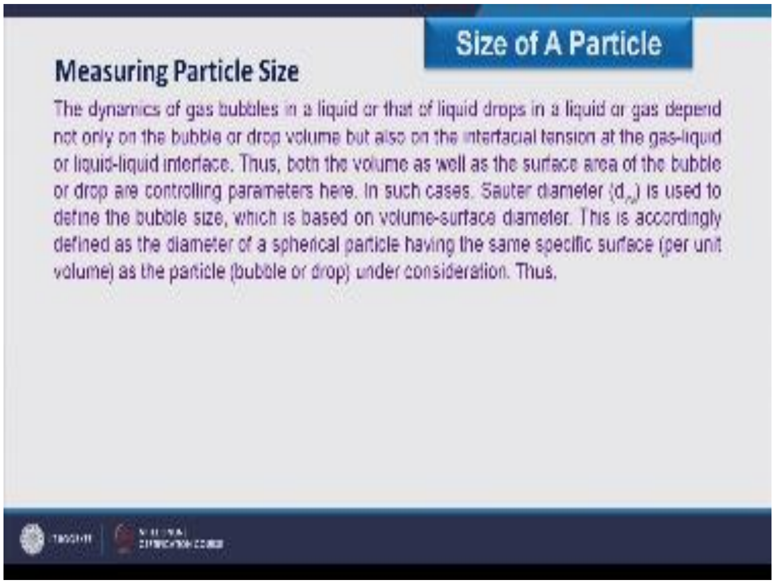

This is accordingly defined as the diameter of a spherical particle having same specific surface, a specific surface means surface area per unit volume as the particle under consideration. So if I am having this S_p that is specific surface which is the surface area per unit volume of the particle.

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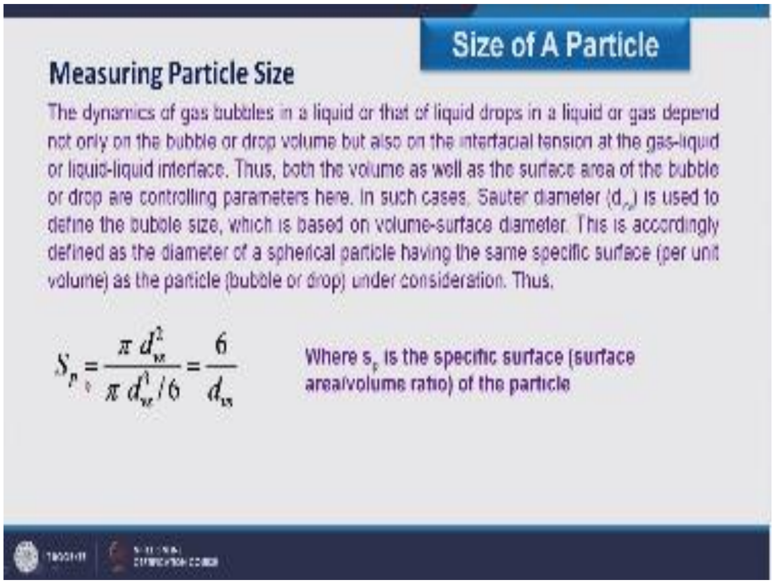

So here we have this surface area of a spherical particle and here we have the volume of the sphere particle. So when we resolve it, it would be equal to $6/d_{vs}$. So the sorter diameter or d_{vs} or volume surface diameter is defined as $6/S_p$. Therefore once the controlling characteristic is specified we can define the size of any irregular particle using above methodology.

So till now we have discussed the importance of size and the different measurement techniques, different definition of size how we can equate this to the spherical particle. So here we have discussed the size of particle it's a different ways to measure the particle size and for time being I am stopping over here and I will continue this lecture in next section, thank you.

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For Further Details Contact

Coordinator, Educational Technology Cell
Indian Institute of Technology Roorkee
Roorkee-247 667
E Mail – etcell@iitr ernet in, etcell iitrke@gmail.com
Website: www.nptel.ac.in

Acknowledgment
Prof. Pradipta Banerji
Director, IIT Roorkee

Subject Expert & Script
Dr. Shabina Khanam
Dept. of Chemical Engineering
IIT Roorkee

Production Team
Neetesh Kumar
Jitender Kumar
Sourav

Camera
Sarath Koovery

Online Editing
Jithin. K

Editing
Pankaj Saini

Graphics

Binoy. V. P

Nptel Coordinator

Prof. B. K. Gandhi

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