Introduction to Mineral Processing
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Lecture - 10
Particle Characterization (Contd.)

Hello everybody welcome back. So, we are discussing about particle size, particle size distribution and I have also try to explain you that, what is the importance of knowing all these characteristics of the particles we are going to treat. There are certain other properties also which are very important for the particles which will control by your separation processes.

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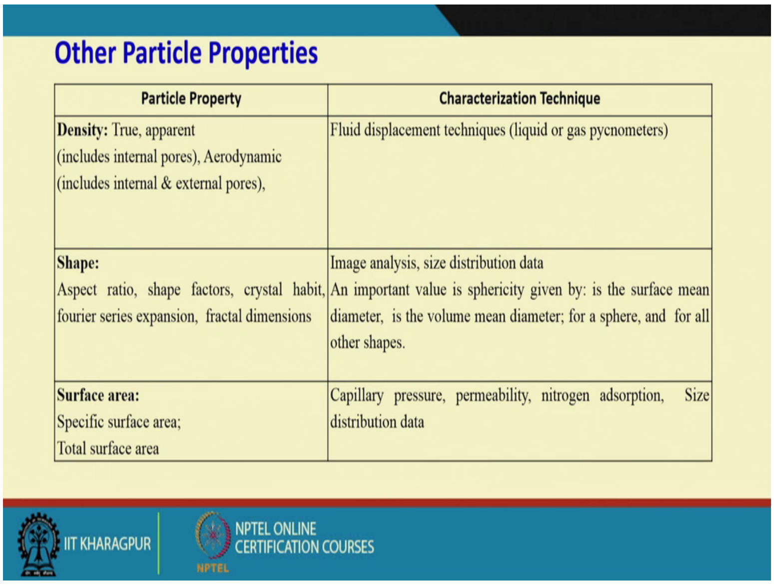

So, a few of them I have listed here. And it is impossible to explain you in detail all these properties and their relevance in mineral processing, but I will try to explain you the most important a few more ah properties which are very relevant for this course. So, the party other particle properties are like density very important to know and the density we will discuss a little bit in a depth. So, the density could be true density, apparent density, bulk density, aerodynamic density like that and the characterization techniques are fluid displacement based techniques. So, please have patience we will come to this topic again, shape we have already discussed surface area we can there are techniques like your capillary pressure, permeability, nitrogen adsorption, size distribution data also we can use to recalculate back the surface area. So, whether we want a total surface area or specific surface area that we have to be very clear depending on your requirement.

Then the porosity many a times we need to know the porosity that is we use a mercury porosimetry technique or maybe nitrogen adsorption technique why porosity is required now suppose I am transporting them into a fluid medium if the material is highly porous though, that means the fluid can get into those particle get inside the particles and then alter the physical properties of the particles by changing it is density and like that you just give me one example.

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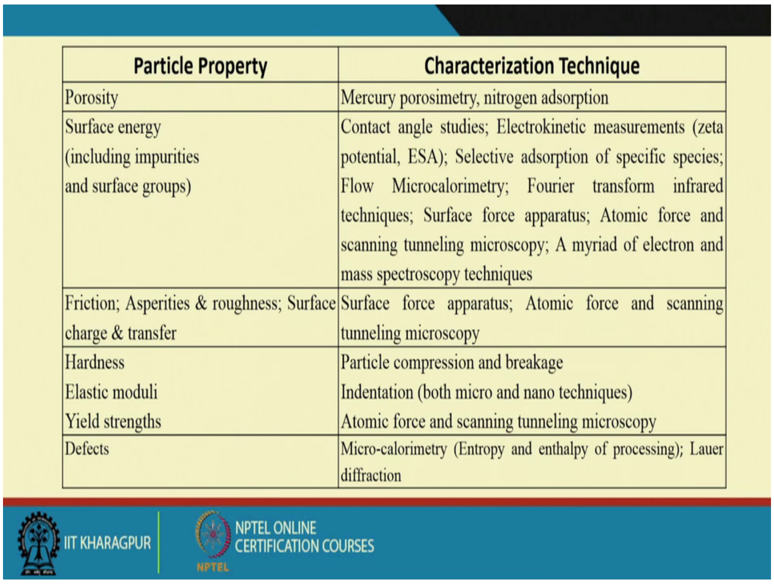

Particle Property	Characterization Technique
Porosity	Mercury porosimetry, nitrogen adsorption
Surface energy (including impurities and surface groups)	Contact angle studies; Electrokinetic measurements (zeta potential, ESA); Selective adsorption of specific species; Flow Microcalorimetry; Fourier transform infrared techniques; Surface force apparatus; Atomic force and scanning tunneling microscopy; A myriad of electron and mass spectroscopy techniques
Friction; Asperities & roughness; Surface charge & transfer	Surface force apparatus; Atomic force and scanning tunneling microscopy
Hardness Elastic moduli Yield strengths	Particle compression and breakage Indentation (both micro and nano techniques) Atomic force and scanning tunneling microscopy
Defects	Micro-calorimetry (Entropy and enthalpy of processing); Lauer diffraction

Then the surface energy friction, asperities and roughness, surface charge and transfer just for example, I would say the your roughness that is your what is the roughness of your particle now suppose you are using a bigger particle and you are basically trying to store into a container which is made of metals, so what type of frictions what type of your erosion related problems you are going to face that depends on the surface roughness and for the very fine particles say when the surface roughness controls your flow behavior of the particles.

Then the hardness means how hard is that because we have to break the particles for liberation. So, if the material if the particle is very hard I have to use a different machine for breaking that and if it is very soft I have to use a different machine to break them. Then the defects like your we use a different techniques for identifying the defects for mineral processing it has got light relevance with in selecting the your say particle breakage related machines you know.

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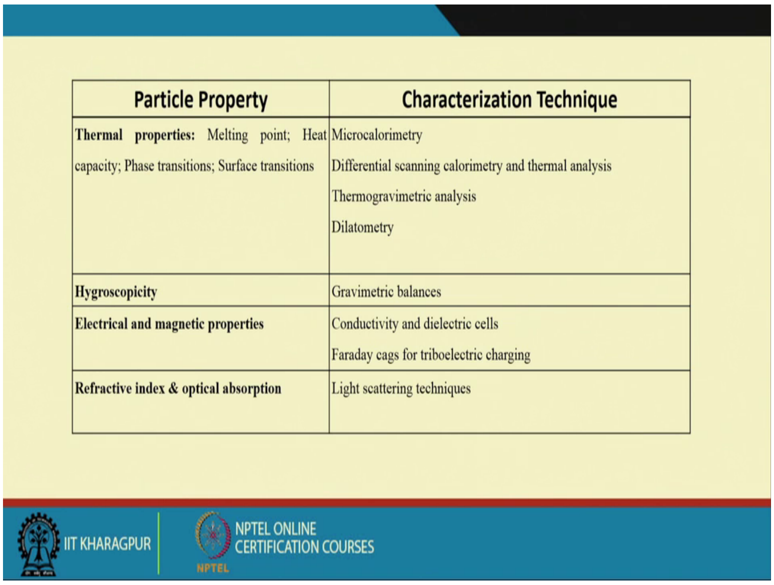

Particle Property	Characterization Technique
Thermal properties: Melting point; Heat capacity; Phase transitions; Surface transitions	Microcalorimetry Differential scanning calorimetry and thermal analysis Thermogravimetric analysis Dilatometry
Hygroscopicity	Gravimetric balances
Electrical and magnetic properties	Conductivity and dielectric cells Faraday cags for triboelectric charging
Refractive index & optical absorption	Light scattering techniques

So, other particle properties many a times we need to know the thermal properties, that is your melting point heat capacity phase transitions surface transitions but for mineral processing activities we hardly use heat. So, it is not much relevant for mineral processing engineers, whereas it is one of the very important property of a particle for in extracts a extractive metallurgist.

Then hygroscopicity that whether it absorbs water or not electrical and magnetic properties they are very important properties sometime for mineral processing people sometimes we use this that is your property differences between two particles for their ideal separate for their separation like, if a particle in an assembly is if some particles are magnetic and some particles are non magnetic then I can use a separator called magnetic separator to separate them out.

Similarly, electrical conductivity if there is a difference between the electrical conductivities between the two particles we can use some kind of your equipment where we can basically use this your the property difference for their separation, refractive indices optical absorption like refractive index like your light scattering technique like your laser diffraction techniques you know we said that we can use it for particle size distribution analysis, but if I have a highly heterogeneous material a very fine particle size ranges and having a wide variation in the refractive indices, then maybe the laser diffraction technique may not be the say most appropriate technique in that cases because it is a single property that is what the laser diffraction technique they use that is a refractive index of the particle.

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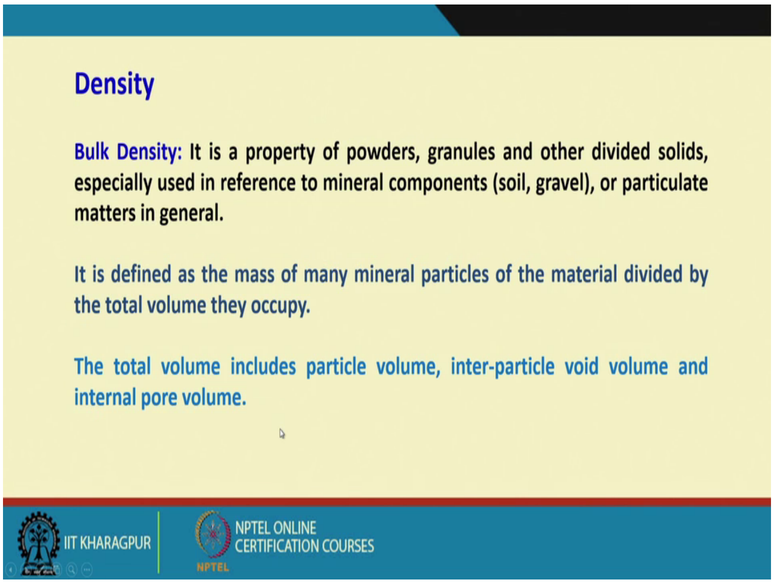

So, let us discuss a little bit at depth as I promised you that is we will discuss more on this density, because it is I think after particle size it is the another property which is very important for a mineral processor. Now the density basically when you are handling large quantity of solids again we do not have the liberty to know the or it is not necessary to know the individual density of the particles because we will be handling the particles in a as a bulk commodity. So, we call it bulk density.

So, bulk density it is a property of powders or granules and other divided solids especially used in difference to mineral corporate soil gravel or particulate matters in general what happens when I am when we are basically handling large quantity of soil there will be entrapped air also. So, what is that bulk I have to basically handle like if I have a volume of this room or say this space is say suppose 1000 meter cube how much of material we can store there the individual density basis if we calculate it because mass is equal to volume into density. So, mass by density if I do it that may that calculation may be wrong because we are not storing the individual particles we are storing a bulk commodity which is having a distribution and you are also storing some air also inside that.

So, I must need to know the bulk density. So, it is defined as the mass of many mineral particles of the material divided by the total volume they occupy, that means simply in simpler term suppose this is a bottle of water I empty this bottle I know what is the volume of this and if I pour the solids into that and I reweighed them I subtract the initial weight of the bottle empty bottle and I know the volume, so based on that I can calculate what is the density because what is the weight of that, so that is the mass and this is the volume.

So, mass divided by volume I get the density. But that density is the bulk density. So, the total volume includes particle volume inter particle void volume and internal pore volume it is when I am pouring the bulk material into this, there will be some void spaces in between the particles that is again dictated by the particle size, distribution and the shape distribution and if the particles are porous then what is the internal pore volume that will also come into picture.

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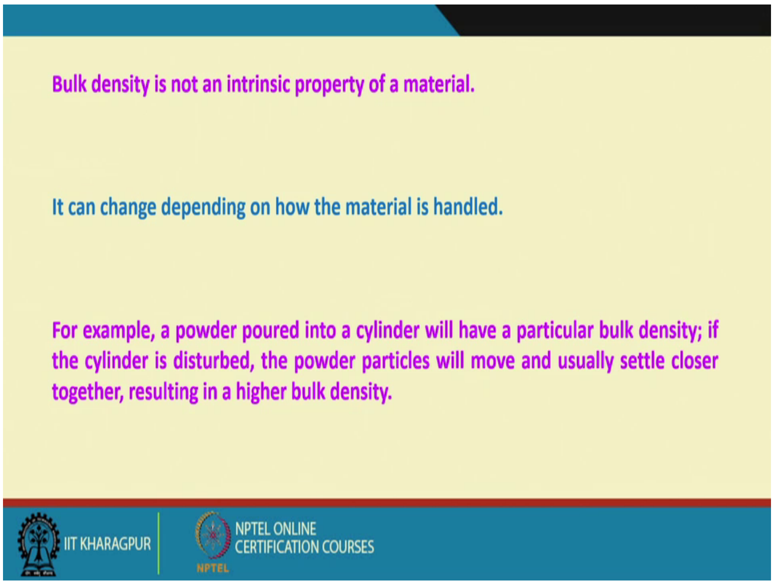

So, the bulk density of this material what I am trying to pour there is different than the individual particle density. Please remember that bulk density is not an intrinsic property of a material, why we are saying this now because it can change depending on how the material is handled like the example I have given that how the material is poured that whether they are loosely packed or if I have some kind of your rearrangements of the particles to decide about their optimum packing so then the bulk density will be different.

So, that is why I have written here that for example, a powder poured into a cylinder will have a particular bulk density, if the cylinder is disturbed the powder particles will move and usually settle closer together resulting in a higher bulk density, even at our home also when we have some suppose example of sugar I want to pour certain amount of sugar into a particular container when it starts overflowing we try to tap them why no because then the particles will try to rearrange themself and there will be more compactness amongst the sugar grains, so I can have more sugar which can be accommodated into that fixed volume.

So, the in one case if you have not allowed it to be rearranged I may be able to pour maybe 500 grams of sugar, but if I try to optimize that I can have 600 grams of sugar, so in both the cases that bulk density will be different and that is why I am saying that the bulk density is not an intrinsic property of a material it changes depending on how the material is handled.

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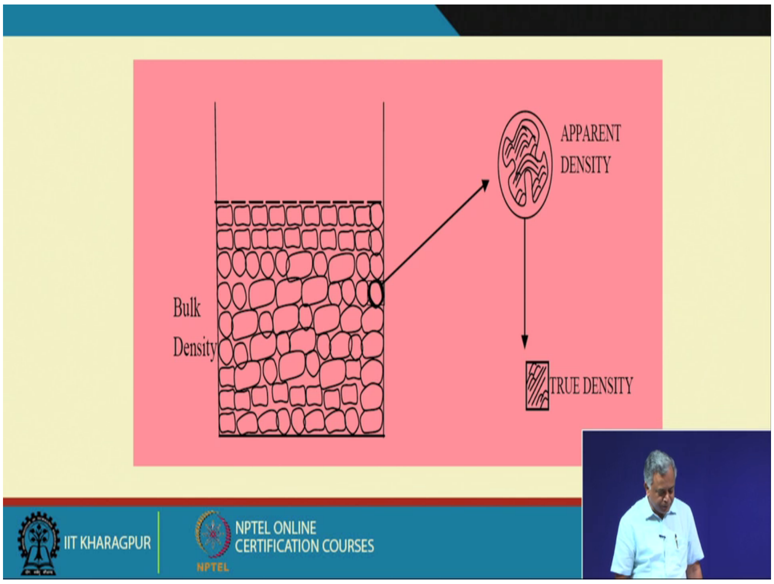

This is what I want to show you through a image that when the materials is basically stacked like this or poured like this. So, whatever is the weight versus weight at volume relationship here that will give you the bulk density and if I take out one single particle from here and if I measure the density of that particle based on the archimedes principle that is the displacement of fluid basis then the density what I will get that is called the apparent density, why we are saying apparent density because we still do not know that whether there are pores here or not inside.

So, that particle may be a single particle, but it may be an agglomerate of various particles and you may have air entrapped into that, you may have moisture interacting to that, you may have some other gases entrapped into that. So, that gives you the apparent density, but if I break this particle to a very fine size as close as to it is molecular size.

Then if I measure the density of that that is when I ensure that this particle is a single particle having a single your element into that and your a single say structure into that and we do not have any pores inside that then if I measure that density that is the true density of the particle. But for mineral processing mineral processors we are hardly worried about their knowing the true density, we are more interested to know the bulk density and many times the apparent density.

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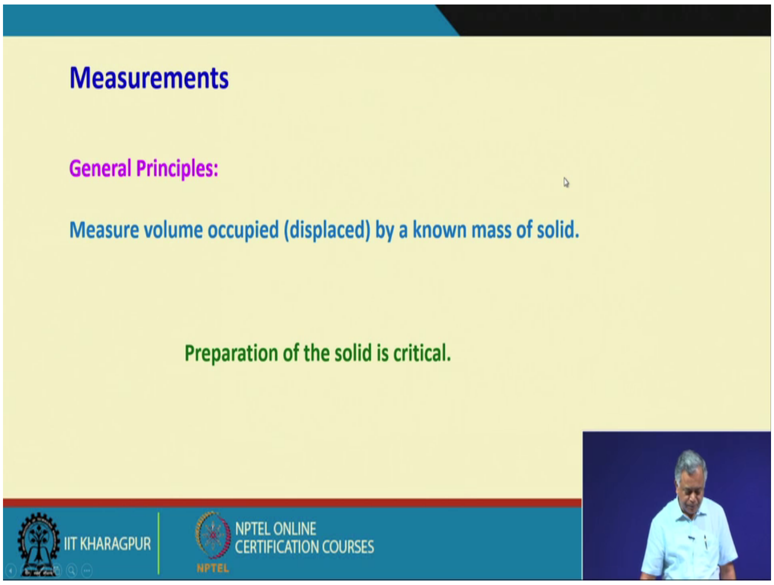

So, when we measure we try to measure the density of the particle the general principle as I said it is based on archimedes principle that is measure volume occupied by a known mass of solid you all know it is a school standard say in the schools we have learnt this. So, in this case very easy to say, but the preparation of the solid is very critical because if I want to know the true density of a particle I have to prepare the that particle to a very fine size range how fine we have to ensure it through microscope that there is no internal pores it is only a single particle it is not an agglomerate of n number of particles like that I will try to show you.

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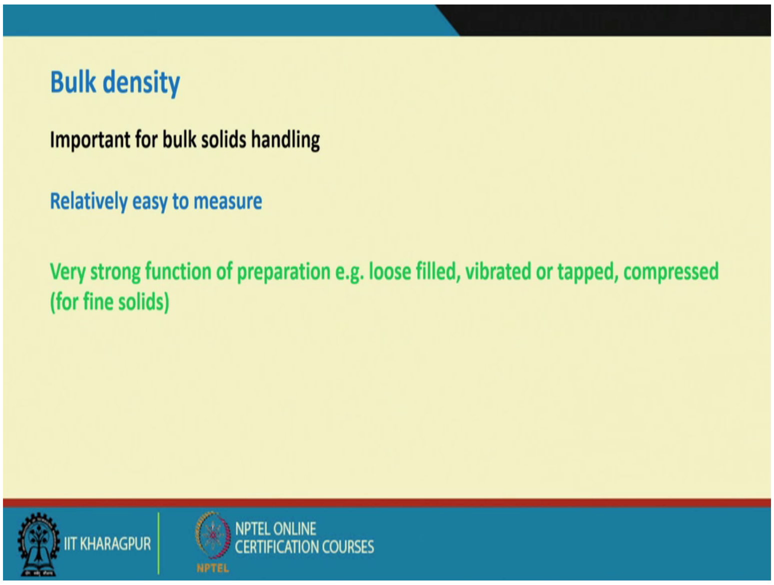

So, the bulk density why we want to know though it gives me the information about the bulk solids handling that is, if I want to handle 500 tons of material per unit hour of say per hour what will be the dimensions of my bulk material handling system that is basically dictated by the volume occupied by this. So, 500 tons to transport it from one point to another point what is the important thing we must know that what is the volume occupied like that; so that we can get to know from the bulk density information and then how this 500 tons of material will be poured into that bulk handling equipment that will decide that what will be the bulk density because how they are arranged.

So, the measurement technique which best suited to the process we are applying that must be used to get this information about the bulk density, however it is relatively easier to measure and as I kept on saying that it is a very strong function of preparation that whether they loosely filled vibrated or tapped compressed and all this.

So, my advice my suggestion is suppose I want to I would like to transport my 500 tons per hour of material through wagons through railway wagons now how the material is poured into a each wagon that will decide that in each wagon how much of material actually you can accommodate, now say suppose is to wagon can accommodate 25 tons of material, so I know that for thousand tons how many numbers of wagons I require. So, this is very important information. But if I change the pouring system that feeling system into the wagons maybe I can reduce the number of wagons, so that is why the bulk material handling system, bulk material handling techniques are very important for mineral processing engineers also.

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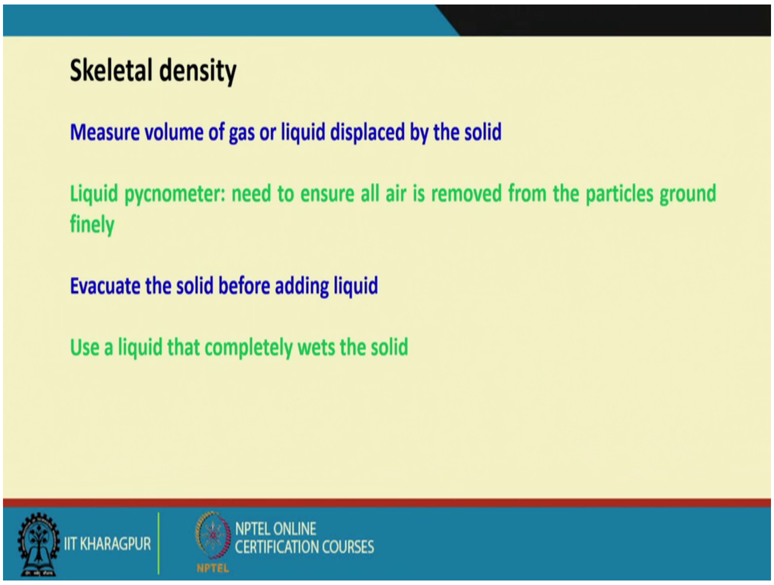

Now one type that is called skeletal density, skeletal density is the basically what I said here that is the density of true density, so skeletal density how do I know again the same principle I will be using that is displacement of fluid basis and what is the volume of that fluid I have displaced. But imagine that you are given a particle whose size is 10 micrometer, now if I try to displace water can we really measure the volume of that water how much it is displaced almost impossible.

So, in that case there are techniques which has come up which has helped us to measure this that measure volume of gas or liquid displaced by the solid, one technique is called liquid pycnometer need to ensure all air is removed from the particles ground finely, that means there is no air entrapped to that and then you are taking not a single 10 micrometer particles you are taking maybe 100 grams of this particles and but before that you have to ensure that is no entrapped air and then you pour it into a liquid pycnometer and then you displace the fluid.

And then you get to know the density of that your individual particles by dividing the number of particles we have used do not get confused to the bulk density because here you have to take extreme precaution to remove the entrapped air.

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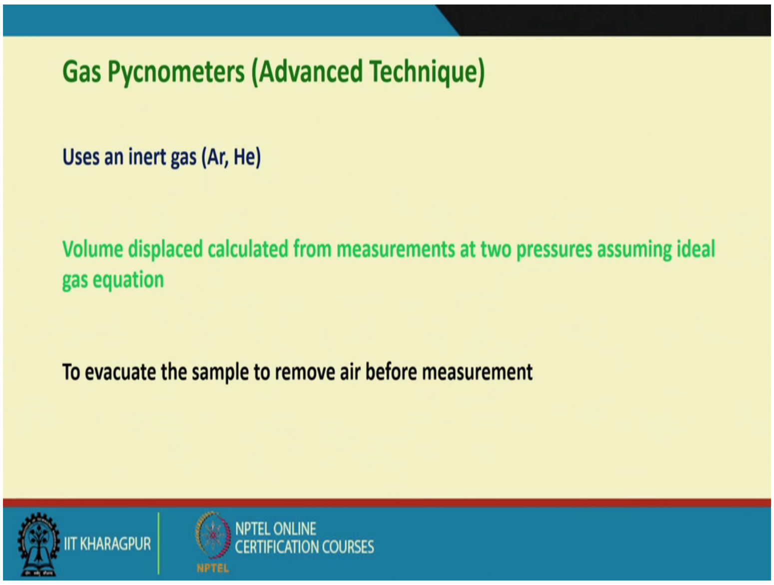

So, or use a liquid that completely wets that solid, that means there is no chance that there will be any entrapped air. There is another technique called gas pycnometer there is a relatively advanced technique it uses an inert gas maybe argon or helium is little bit more common. So, the volume displaced calculated from measurements at two pressures assuming ideal gas equations I am not getting into the details of that, so the gas pycnometery method you can get to know the skeletal density of very fine particles.

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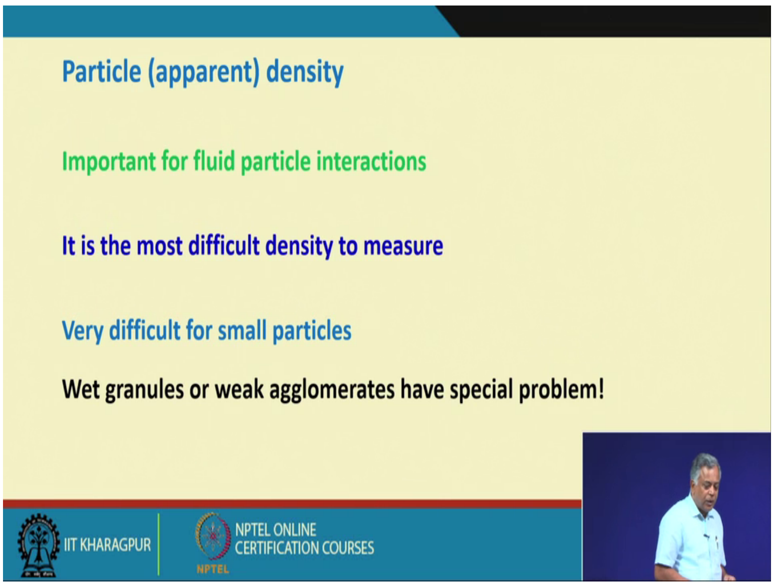

The most critical most difficult part is knowing the particle apparent density, but it is very important while dealing with fluid particle interactions and most of the mineral processing operations they are wet. So, this information many a times is a vital information for designing your separation equipment, it is very difficult for small particles to measure the particle apparent density. Because you have to ensure that the inherent force of that particle it should not be occupied by a fluid other than the whatever the gas or air it has got already because when I am dropping it into a water the water may get into inside that particle through the pores and can displays the air and I can have a different density then what exactly it is.

So, I have to ensure that the particle density, apparent density what I am measuring that is exactly what it was before I dip that particle into the water. So, there are different techniques for that you can use a woks method that is you have a basically a coating of wokses and then you know that how much is the coated material you subtract it from that and then you displace the fluid that is the water and if it is for very fine particles it is very difficult to know the apparent densities.

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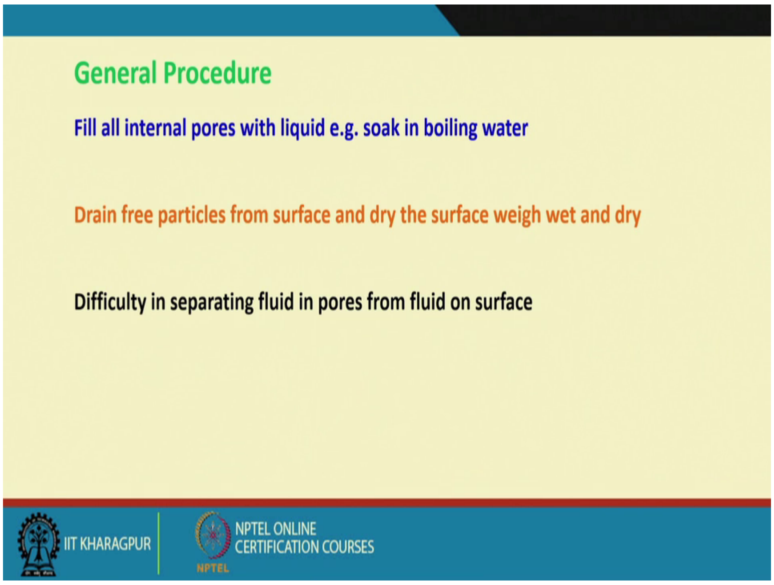

So, general procedure for all internal pores with liquid that is soak in boiling water, that is fill all internal pores with liquid may be that initially the dry solid what is the weight of that and you soak it into a boiling water to ensure that all your pores are filled up with water then you reweigh that by cleaning the surface of that particle to ensure that there is no there is hardly any water into the surfaces. So, you know the internal pore volume, but the problem is the water can only get inside if the pore is open pore, what I am trying to say that if I have a pore inside a particle a big particle which is not at all exposed in the surface how the water will get inside.

So, there is a chance of having a erroneous result drain free particles from surface and dry the surface weigh surface wet and dry so that means the basic technique what we are trying to do that is we want to know that how much is the pore, volume and then you subtract it from the actual weight of the sample, so then you get to know what is the density of that. So, it is very difficult in separating fluid in pores from fluid on surface how do I know that this fluid is in inside the surface or it is inside the pores. So, you have to take extreme precaution you have to very clear about the reproducibility of the data and the accuracy of the data.

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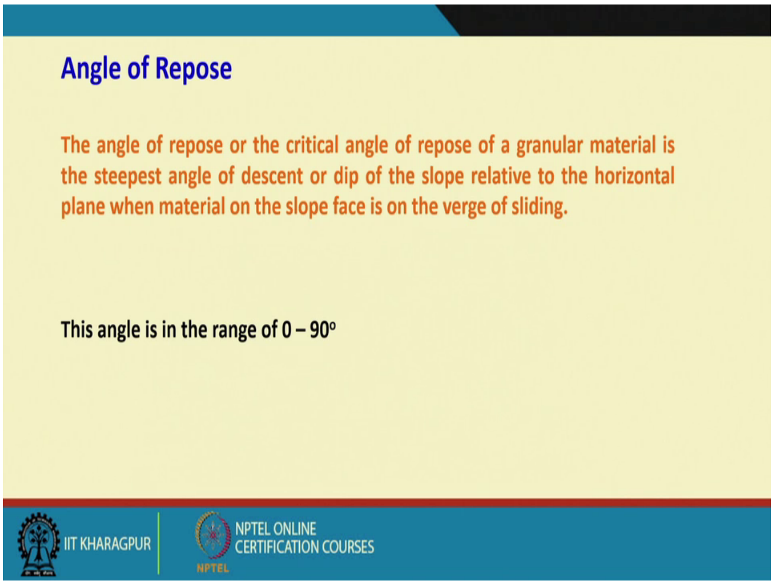

So that is in brief about the density measurements ok. Now, there is another physical property from a material handling point of view, because any mining engineer or any mineral processor or even the extractive metallurgist that dealing with large volume of particles I kept on repeating this. So, we are more interested in knowing the behavior of the bulk solids.

Another important property is the angle of repose. So, what is that angle of repose the angle of repose or the critical angle of repose of a granular material is the steepest angle of descent or dip of the slope relative to the horizontal plane when material on the slope face is on the verge of sliding long sentence I could have splitted it into two or three sentences. But what I am trying to say that suppose I have got 500 grams of sand and I keep pouring gently onto this surface. So, what will happen initially they will be spread and then you will find that there is a cone formation is there. So, angle of repose is that is the cone that is the cone you are having, so what is the angle I will show it through a picture like this.

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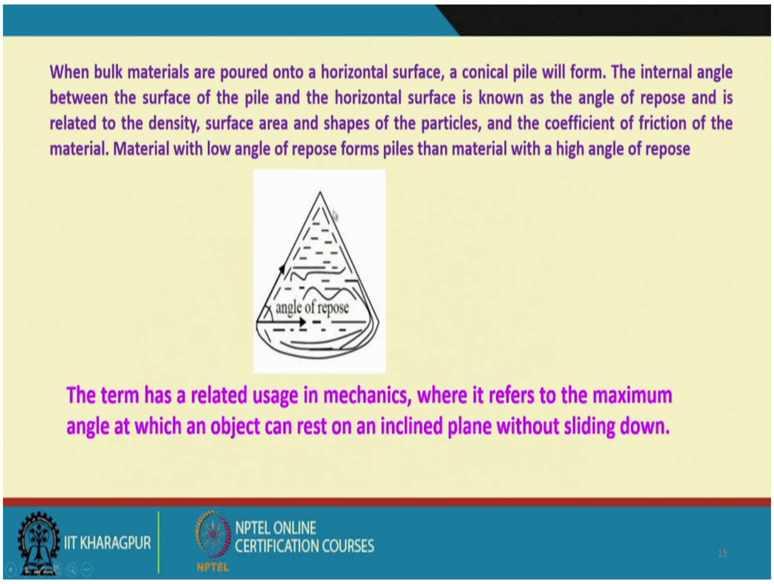

That is you have got a cone and that is the angle with the horizontal what is the angle this is called the angle of repose. Why it is important to know the angle of repose it has got many applications, just imagine that you are trying to transport material through a conveyor belt is moving like this and you have got a hopper which is continuously feeding the material to the conveyor belt and conveyor belt has got a specific dimension like width. So, per unit length with that fix to it how much of material can be accommodated that is very essential to know, because say suppose I have to transport 100 tons per hour, so what would be the dimensions of this what would be the belt speed and everything I must know depending on this. So, how the material is being say while pouring it how they are being basically say distributed are they getting flattened immediately or they are having some cone shaped.

So, as the angle of repose which will decide that per unit length of that conveyor belt how much of material you can transport, another application is like I have a stockpile many times that is you want to stock you want to store your material before final dispatch. So, you have got a fixed land space so you have stored the material, but before that you have to calculate back that I have to store around 50000 tons of material. So, how much of land area will require to store that 50000 tons of material that will depend on what is the angle of repose because how high you can go because the height also you want to use. So, how high what is that height you can use that will be decided by this angle of repose, there are many other applications.

So, this angle is in the range of 0 to 90 degree. So, look at this so if you have a very say your high angle of repose, that means it is very close to the vertical so that means, that your material say suppose it is just like your vertical it is impossible to have any angle of repose like that it is generally like this cone shaped. So, the flatter they are that is if the angle of repose is less, that means they are more flattered that means every 0 degree the angle of repose that means, there is no cone formation. So, what will happen the surface area requirement to accommodate a particle a particular quantity of material will be more than particle having higher angle of repose.

So, which controls the which controls this angle of repose is it fixed for any particle class again it is a function of particle sizes, particle shapes because the angle of repose is basically a resultant a ultimate result between the your static friction between the particles. In another case like your in mechanics that is it refers to the maximum angle at which an object can rest in an inclined plane without sliding down, like if I have an inclined plane and if I have a car in a neutral position that whether what is that maximum angle it can stand still because of it is center of gravity because after a critical angle if you put it into a neutral gear it will try to roll back and if you do not have your and that is the very purpose of having your say hand gear a hand break. So, that is not exactly the angle of repose but that is the basically we can do the force balances and we can calculate it back so similar behavior the particles are also having the particulate mass is also having.

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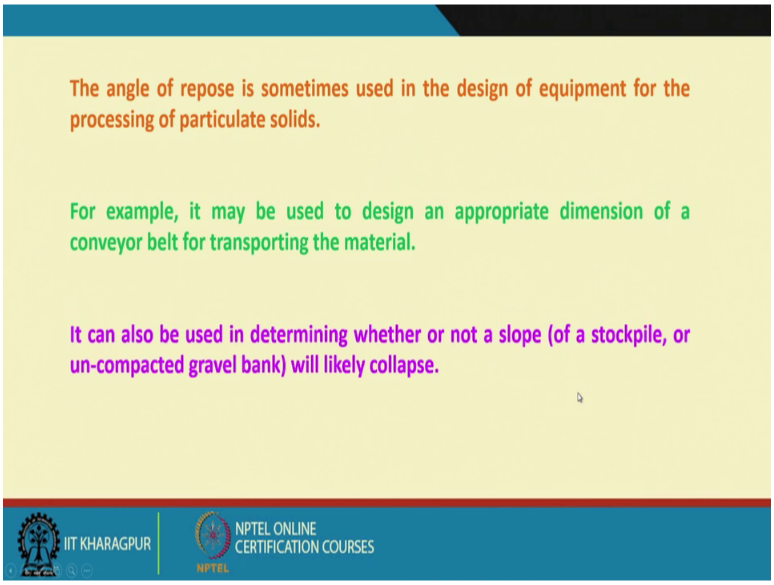

So, the angle of repose is sometimes used in the design of equipment for the processing of particulate solids, I would try to explain it a bit more in my next lecture

Thank you very much.