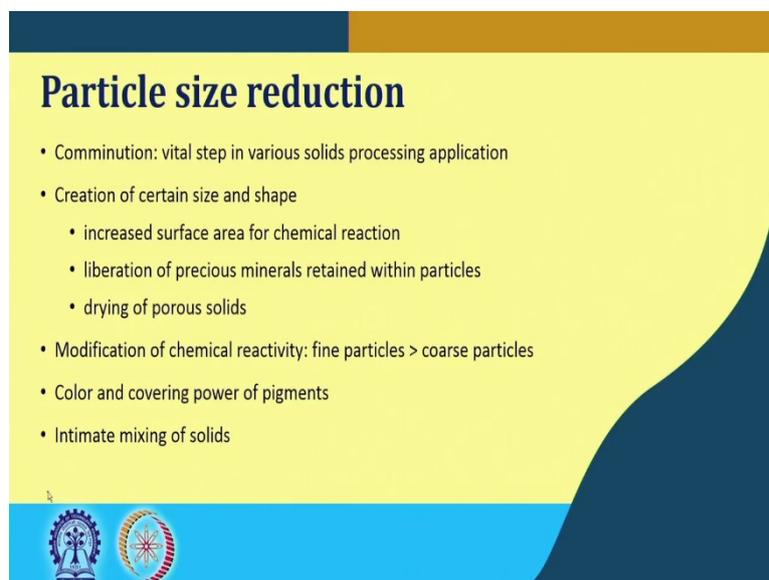


Fundamentals Of Particle And Fluid Solid Processing
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Lecture - 41
Particle size reduction

Hello everyone and welcome back with a another new topic on the Fundamentals of Particle and Fluid Solid Processing. Today we will be looking at Particle size reduction.

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Particle size reduction

- Comminution: vital step in various solids processing application
- Creation of certain size and shape
 - increased surface area for chemical reaction
 - liberation of precious minerals retained within particles
 - drying of porous solids
- Modification of chemical reactivity: fine particles > coarse particles
- Color and covering power of pigments
- Intimate mixing of solids

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The first of all why such particle size reduction is necessary. This particle size reduction or in popular term it is also called comminution is a vital step in various industrial applications that handles the solid particles. Now, not necessarily it is important but also sometimes it is very essential. The reason is that it creates a certain size of particle different shape of particle.

By doing so, it increases the surface area that is available and that is important in several applications while chemical reactions happens because the reaction rate actually depends on this available surface area. So, by this size reduction we increase the surface area of the particle. There are also applications when several precious or valuable minerals are retained in within the particles or say you know very inaccessible pockets of the particle of a big cluster of the chunk of a big rock. Now in that case if we break this solid chunk or the bigger particles into smaller pieces then this liberation or extraction of this valuable mineral becomes easier.

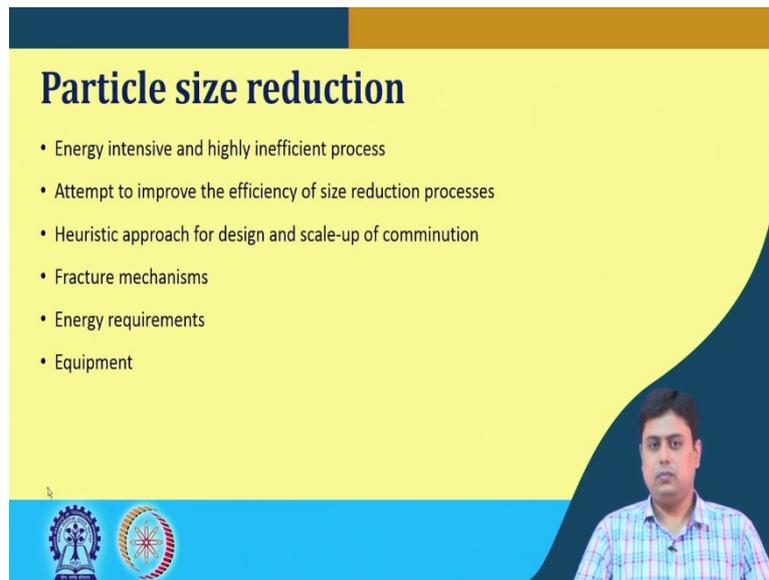
Not only that by creation of this increase surface area and by doing this size reductions in leaching, that means, when we try to extract get one component from the other there this depth of penetration of this liquid through this particles becomes lesser and lesser. So, it not only helps in having increased surface area but also helps in enhanced leaching operation. Also, in case of say porous materials ok, or the materials where it is required to make it in a dryer condition.

So, there this drying of the porous solids easier when these materials are broken into pieces because then those cracks or the fishers are then exposed to the atmosphere and this drying can happen very fast. So, this size reduction all these benefits are there, but certain point has to be remembered that if we modify this surface to a great extent or a reduce the size to a greater extent then there are chances of modifying the chemical reactivity of this not that solid particle, and this reactivity increases in case of fine particles than the coarse particles.

Moreover when we have this fine particles say in a cases of pigment the coloring agents this coloring and the covering power of the pigments depends on their size of very fine material can look different in color than its bulk materials and on top of this if we want to have different solids to be mixed this intimate mixing of solids are enhanced when the particle sizes are reduced and these are like very extensively applied cases because say when we have to mix two components of solids to get something out of that such kind of mixing in a dry condition becomes easier when the size of the particles are reduced to a certain limit keeping their identity same.

So, these are the various benefits of size reductions there are certain issues with such size reductions because creation by doing the size reductions we are creating more available surface and that comes with the expense of energy.

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Particle size reduction

- Energy intensive and highly inefficient process
- Attempt to improve the efficiency of size reduction processes
- Heuristic approach for design and scale-up of comminution
- Fracture mechanisms
- Energy requirements
- Equipment

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Now, this is quite energy extensive process the size reduction process and very inefficient process because this creation of a new surface takes a lot of energy say in terms of numbers the energy that is typically supplied in these size reducing a equipments hardly point one to two percent are converted in creating this new surfaces.

So, which means there are several research that have tried to improve this efficiency of size reduction processes there has been a lot of studies and the in directs indirectly it can be said that which means there are a lot of study has been also done that why or how to create this new surfaces or how to fracture a material because by doing so we can divide a bulk or say break the bulk of a particle bulk size of a particle to smaller pieces.

So, there has been a lot of study on both the fronts that how to increase the efficiency as well as why it is so inefficient or what are the fracture mechanism what are this particle how it can be broken that kind of study has been done. So, what we will be discussing in this lecture is those findings those empirical findings those experimental findings the suggestions that which kind of particles will break easily what kind of law is applicable to calculate the estimated energy for this particle size reductions. So, that means is there no such rule that how to calculate its energy requirement so that I can go for design and scale up.

There are available they are available but the point is that but this manufacturing industries still depends on the heuristic approach of design and scale-up for this comminution process that means, it beliefs or it relies mostly on the past experience and the practice that is

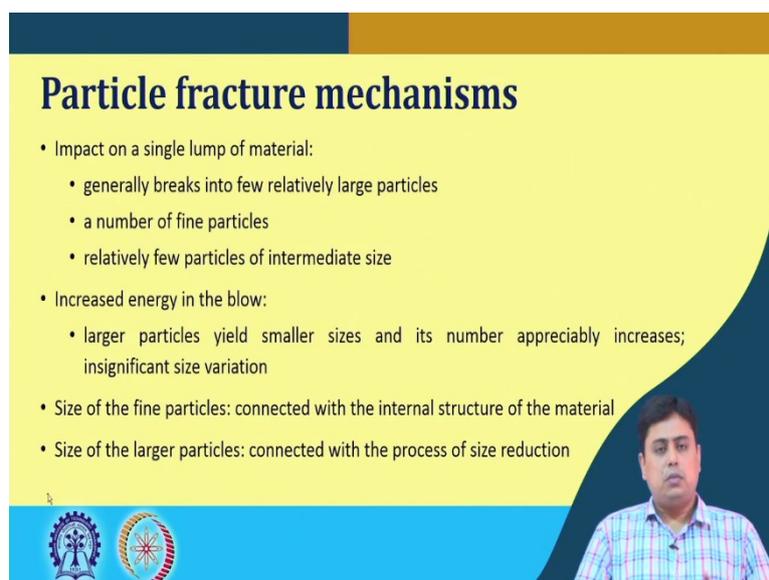
currently going on that how much we can extract from certain wall not wall following a certain rule or say law no generic law is there.

So, it mostly comes from the previous experiments. So, which means as I said here in this topic we will be looking at different fracture mechanisms because that is one of the mandatory step to have the reduced size of the particle. We will look into the energy requirements as we have mentioned that this is a very energy intensive process and wide so, that we can see from the fracture mechanism as well as how to estimate that amount of energy and then we will look into the brief discussion on the different types of equipment that are available for different types of size reduction.

Different types of size reduction means different stages of size reductions because it is logical that if you take a block of particle say 1 meter block of a particle kind of a rock in a single stage you cannot make it to say 10 micron size particles it has to go through a sequence of operation one equipment is not effective will not be efficient to have this a single stage operation.

So, at which stage what kind of equipment should be used we will look into that and in one equipment we will put our particular focus that we will see in a later section.

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Particle fracture mechanisms

- Impact on a single lump of material:
 - generally breaks into few relatively large particles
 - a number of fine particles
 - relatively few particles of intermediate size
- Increased energy in the blow:
 - larger particles yield smaller sizes and its number appreciably increases; insignificant size variation
- Size of the fine particles: connected with the internal structure of the material
- Size of the larger particles: connected with the process of size reduction

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So, this particle fracture mechanism say you have taken big lump of particle and there is a single impact on that with a certain intensity of energy or force. Now generally it breaks

into few large particles and a number of fine particles plus relatively few particles of intermediate sizes.

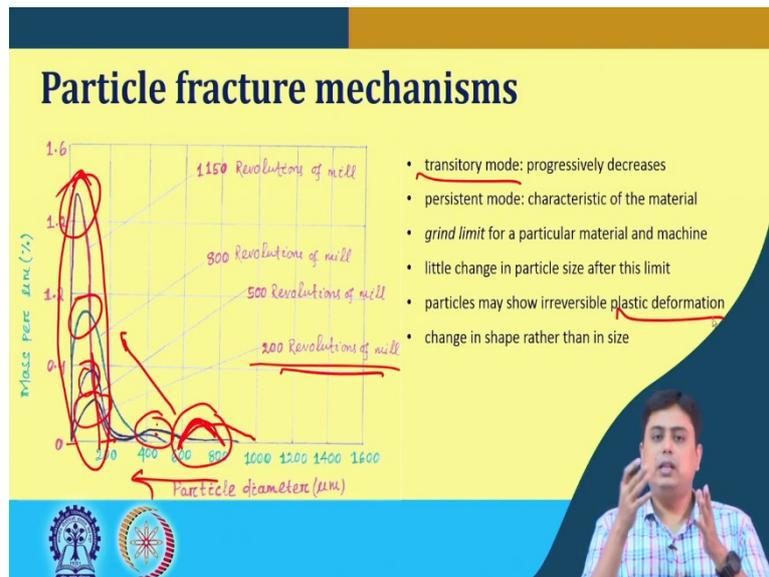
So, which means the size aggregations is something like that you have a more number of relatively large particles followed by intermediate size particles and very fine particles of fuel in numbers. Now if you increase the energy of that blow or the impact what will happen this larger particles will create several more smaller sizes further. So, the number will appreciably increases but there will be insignificant variation in size of this small particles. So, initially you had say rock with a certain impact when it is comes on to this it goes into several large particles fewer intermediate size particle and fewer lesser number of fine particles.

We increase the intensity of the blow. What happens these large size particles will create more and more finer particles. So, the number of finer particles will increase whichever were there in the earlier state but the size of these finer particles will not increase significantly. So, which means the size of the finer particles are actually connected with the internal structure of the material say at the atomic level and the size of the larger particles are connected with the size of the process of the size reduction.

Which means by the way this impact is coming onto this rock say the method of application of this load that is being put into the solid rock. So, the large size particles or if I say in a different way that this big rock from coarser particle largely depends on the process of size reduction the way the force is being applied but the structure of the or the size of the finer particles if we try to make it more finer we will see that that is more energy intensive process because it is related with the internal structure of the material.

We have to overcome certain forces at the molecular level or the atomic level. So, these are the hypotheses and it has been seen experimentally verified that this is indeed true.

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So, researchers have done one experiments or couple of experiments and have come up with a interesting result. Say, we have taken a certain size range of particle say initially we took 60 to 1000 μm of the particle or 60 to 800 μm of the particle. So, say this is the size distribution initially and then in crusher or say in milling operation we will see what is that in a size reducing equipment this is crushed. Ok, now this crushing as it is intensity depending on the rate of application of load on the particles or the impact on the particles.

So, it has been seen this revolution means revolution of the mill means this intensity rate of the equipment. So, as it increases from this big size particle or when from where we started it goes in this direction this size distribution. So, after a certain revolution or certain intensity it has been seen that there are two peaks on the size distribution.

So, this is the first peak and this is the second peak which would occur because the size is reduced from this way in this way from 600; it is going to 400, 200 in this size. So, the size distribution will have two peaks initially and as the intensity or the power of crushing is increased that first mode or the first bomb will be in decreasing towards giving a single mode size distribution. So, this mode that is that comes in transit are until the complete size reduction has happened is called the transitory mode which progressively decreases with increasing the intensity.

And the other mode is called the persistent mode because it is persistently there which is the characteristics of the material because it is now related with the finer size of the particles. So,

it is the characteristics of the material. So, which means by looking at these results it can be concluded that there will be a grind limit for a particular material as well as the equipment or the machine. After this grind limit there will be hardly any change in particle size sees how the narrows have size distribution has become.

So, it is in between 0 to 200 or 100 of the μm and the particles may show some irreversible plastic deformation after this limit which means this plastic deformation means which is irreversible deformation of the particle. So, permanent damage to the particle. So, they will show this irreversible plastic deformation after or beyond this grind limit and after that this change in size will be insignificant, but the force in excess can result in shape change of the particles.

So, this is a kind of a common process that has been seen when we go from size reduction from a big rock to coarser particle, intermediate particle and fine particle. So, with increasing force or the impact we have two modes of size distribution, one the first mode that comes we call the transitory mode and the second one is the persistent mode because it increased it remains because it is the characteristics of the material and there is the grind limit beyond which the grind limit applicable for both it is the limitation of the equipment as well as the characteristics of the material.

So, beyond that limit the particle size will not be further reduced by that particular equipment. One way of reducing further can be given to a different equipment as a field and that brings to that cascade of operation of sinks of sequence of operations in different stages because this grind limit exist. So, beyond this grind limit the size will not change, but the shape may alter.

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Particle fracture mechanisms

- energy required: related to the internal structure of the material
- process comprises two parts:
 - opening up any small fissures which are already present
 - forming new surface
- a material containing a number of small cracks:
 - breaks along those fissures
 - large pieces break more easily than the small ones
- fine grinding more power intensive
- can be impeded by the tendency of forming aggregates

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So, the energy required actually is related to the internal structure of the material and the whole process of size reduction broadly categorized in two parts. One is the opening up of any small fissure or crack that is already present and forming a new surface as that crack propagates or it create branches. So, material containing a number of cracks bricks along those fissures or those cracks and the large pieces break more easily than the smaller ones and this smaller one if we try to grind them it requires more and more power.

Furthermore, these small particles when it becomes sufficiently finer as its surface characteristics can change the surface properties can change and the whole process can be impeded by the tendency of forming aggregates by this fine particles.

So, this these things has to be kept in mind. So, it is not just that I have this equipment any material I can grind to a certain limit that does not happen. We have to characterize the material before we put into appropriate grinder or crusher to crush them. So, that is why material testing is important step prior to its size reduction. So, now, in case of say limestones in this cases these aggregates forms by the cohesive force between the particles.

So, based on the property of the material or the type of the material the bottom line is that such kind of selection of the grinder or the size radiation size reducing equipment has to be there.

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Particle fracture mechanisms

- Process efficiency is influenced by:
 - manner of load application
 - its magnitude
 - nature of the force (compressive/impact/ shearing)
- Insufficient applied force not exceeding the elastic limit
 - material is compressed
 - energy is stored in the particle
- On removing the load: the particle regain its original condition without any useful work
- The supplied energy dissipates as heat and no size reduction

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So, this process efficiency of any equipment or grinder is influenced by couple of factors or mainly three factors one is the manner in which or the way by which this load is applied. Secondly, its magnitude and the other important component is the nature of this force that is being applied either it is a compressive force is it an impact is it a sharing phenomena.

So, how the force is being applied. Now, all these factors influences the process efficiency as well as the equipments are designed based on this criterias. Let us say one of the equipments in this in doing this size reduction operates in compressive forces. The others can operate it in impact forces the other machine can impact in shearing forces. Now all those this nature of forces basically influences the end product there is a limit that this kind of forces eventually reflect in creation of new surface for a certain size range.

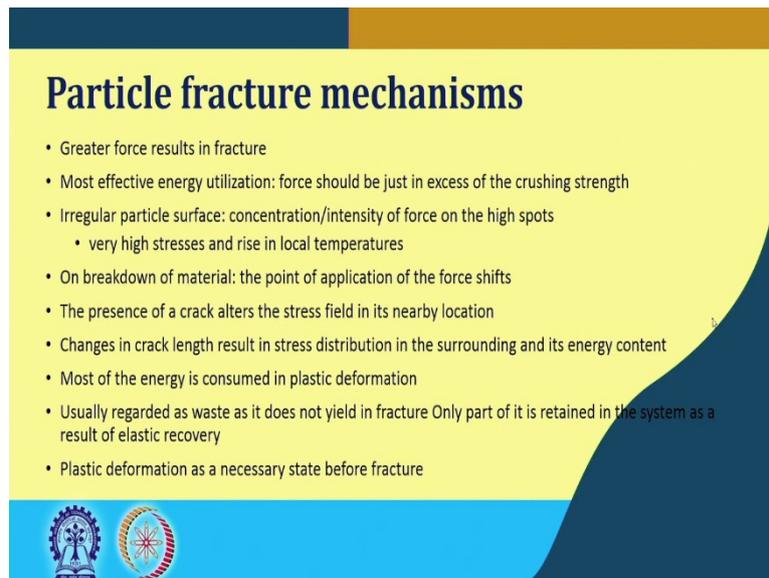
It cannot handle the complete range of the size range for any particular application. So, what does that mean. Say this sharing operation, so, you can handle the fine particles to further finer particles. The coarser particles to finer particles we may need any combination of these forces or any other single force type of force can handle such scenario. So, when a insufficient force is applied that does not exceed the elastic limit that the size reduction is not happening the material is compressed and the energy is stored in the particle.

What does this mean by this elastic limit that if we remove that load the solid regains its original condition without any useful work. So, which means the energy that we have supplied has basically gone into waste in terms of size reduction because it did not affect that

but the supplied energy dissipates as heat and this being stored in the particle. So, we have to cross this elastic limit to make this size reduction to happen and there is the plastic limit. So, we have heard these two terms one is the plastic deformation the other one is the elastic limit.

So, beyond this elastic limit this plastic deformation will happen.

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Particle fracture mechanisms

- Greater force results in fracture
- Most effective energy utilization: force should be just in excess of the crushing strength
- Irregular particle surface: concentration/intensity of force on the high spots
 - very high stresses and rise in local temperatures
- On breakdown of material: the point of application of the force shifts
- The presence of a crack alters the stress field in its nearby location
- Changes in crack length result in stress distribution in the surrounding and its energy content
- Most of the energy is consumed in plastic deformation
- Usually regarded as waste as it does not yield in fracture Only part of it is retained in the system as a result of elastic recovery
- Plastic deformation as a necessary state before fracture

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So, greater force results in fracture. So, beyond this elastic limit if we increase our force it in it creates fraction and the most effective utilization of this applied force would be when it is just exceeding or marginally exceeding this crushing strength of the material. Now, the particle surface is of irregular in nature. There are hardly any smooth surfaces ideally that is not there. So, this irregular particle surface has some high and lows spots.

So, that means this applied load or applied force actually heats on the high spots or there is a concentration of the intensity of the forces on these high spots. So, there we have very high stress and the rise in local temperature. On its breakdown, when the rate material breaks, this point of application of this force actually shifts or changes alters at different position because that is no more the high spots.

Now presence of crack basically alters the stress field in its nearby location and the changes in crack length result in the stress distribution in its neighborhood and the energy content. So, most of the energy is consumed in plastic deformation, permanent deformation of the particle and it can be regarded as waste at it does not result in fracture and only part of this

applied force or the energy will be retained in the result of elastic recovery. Now, it can also be thought of in this way that if the plastic deformation does not occur the fracture would not happen. So, which means the plastic I mean you cannot avoid the plastic deformation and directly go into introducing a fracture.

So, the plastic deformation is a necessary state before the fracture propagates or fracture introduced and then the propagation will happen and then this size reduction will be affected. So, we will continue this discussion in the next class as well. So, what we have learned today is the process of size reduction different theories behind this why the size reduction happens the fracture mechanism how a fracture can be introduced and we will later see how this fracture propagates and creates different size of the particle as well as the how much energy is required for this new surface creation. This will be dealt in the next class until then.

Thank you for your attention.