Mechanical Unit Operations
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Lecture 10
Equipment for Size Reduction – Ultrafine Grinders and Cutting Machines

Welcome to the MOOC's course Mechanical Unit Operations. We are discussing Equipment for Size Reduction. In previous two lectures we have seen different types of equipments under crushers category and grinders category. This particular lecture will be discussing equipment for size reduction under ultrafine grinders and cutting machines category.

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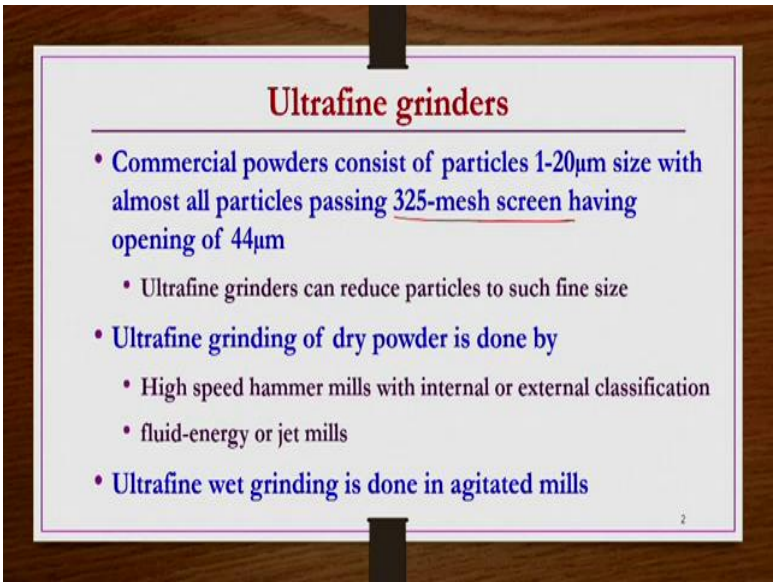

So, let us start with a you know for the case of a ultrafine grinders so in general what happens commercial powders need to have a particles in the range of 1 to 20 microns on the average. Sometimes particles may have a, you know slightly oversized compact the 20 microns but almost all particle should pass through 325 mesh screen having opening of 44 microns in general. So, that is the requirement in any of the commercial powder in general.

So, in many of the commercial powder you need to have a finer particles of size 1 to 20 microns average size in general, whereas almost all particles passing through 325 mesh screen having opening 44 microns. So, such fine kind of particle if you wanted to have it is better to go for kind of a ultrafine grinders. Indeed ultrafine grinders can reduce particle to such fine size.

So, ultrafine grinding of dry powder can be done by two different types of mills. So, one is the high speed hammer mills with internal or external classification. So, they are more or less like

a hammer mills you know but speed is very high. This hammer mills, in addition to the hammer, whatever the rotor in hammer Mills, the rotor consisting of several hammer 4 to 8 hammers, swinging hammers in general. But here in addition to this hammer there will be some kind of a classifier also, so that to take the product away from the, you know crushing area and then collect into the product collection vessel.

So, the other type of a ultrafine grinders used for dry powder is fluid-energy or Jet mills. Fluid energy mills where a kind of a steam or a dry air is in general used at high speed as a kind of medium for size reduction in this fluid energy or Jet Mills. Whereas Ultra fine grinding of wet material is done by agitated mills. So, we will be discussing in this lecture about the hammer mills with internal classification in fluid-energy mill then some type of agitated mills will be discussing.

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Classifying hammer mills or hammer mills with internal classifications, what we have a set of swing hammers is held between two rotor disks as in a conventional machine but in addition to hammers, the rotor shaft also carries two fans. Why these fans are required? These fans draw air through the mill toward the drive shaft and then discharge into ducts leading to product collectors.

So, having this additional any arrangement makes a kind of a classification of the material so that is the reason this hammer mills with these fans are known as the hammer mills with internal

classification. On, the rotor disks, there are short radial vanes for separating oversize particles from the required product size.

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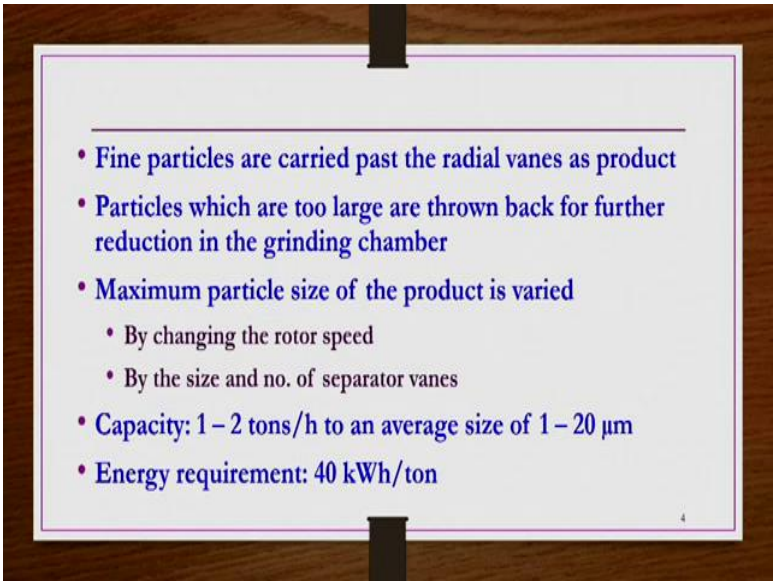

So required whatever the fine materials are there they are carried pass the radial vanes as product, whereas the particles which are too large or thrown back for further reduction in the grinding chamber. Maximum particle size of the product is in general varied by changing the rotor speed or by changing the size and number of separator vanes. The capacity of this hammer mills with internal classification is in general 1 to 2 tons/hr producing the product of average size 1 to 20 microns in general whereas the energy requirement is 40 kWh/ton of the product

But this is about the hammer mills which is operation is more or lesson same as in the case of hammer mills, but here we have a classifier, the fans and vanes are provided so that you can separate the product as oversized and undersized product. Undersized products can be taken as a kind of product. Oversize material can be fed back to the crushing chamber for further classification otherwise rest of the operation is quite similar as the hammer mill such that we have already discussed. The classification, the separation of the product as oversize and undersize is done by the fans and separating vanes which are mounted on the rotors.

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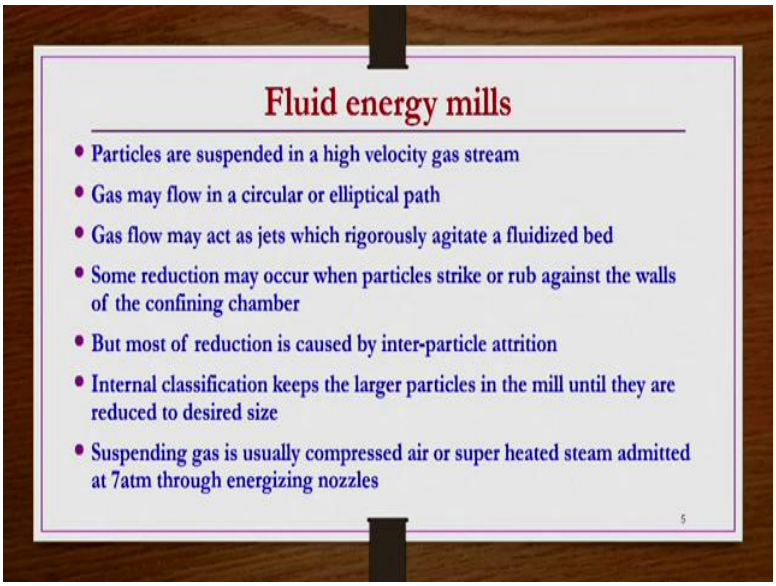

Then Fluid energy mills, actually this is done by you know, the size reduction is done by the high speed fluid medium, in general taken as a kind of fluid medium like steam or dry air is generally taken at high speed. So this medium is passing through the particle, so then fluidizing the particles also finer particles also, so there will be attrition amongst particles as well as the particles coming into contact with the walls of the container, the walls of the equipment, then also attrition takes place and then size reduction takes place.

At the top of this fluid energy mills there will be a kind of a separator where the particles are in separated kind of in a two different ranges. The finer particles which are taken to the cyclone separator and from cyclone separator the fine material are collected into the bag collectors whereas the coarse or the oversize material are fed back into the fluid energy medium, fluid energy mill which is again and again circulating under the required size reduction takes place, so that is the basic principle in this fluid energy mill.

Particles are suspended in a high velocity gas stream in this fluid energy mills and then gas flow in a circular or elliptical path, that is the depending on the design of the fluid energy mill that we have, the gas flow maybe circular or in elliptical path. Gas flow may act as jets which rigorously agitate the fluidized bed, fluidized bed is consisting of the particles which are to be size reduced, which are to be crushed or the size of which are need to be reduced to further smaller fine sizes.

So, the whatever the gas flow or the steam is there that will be acting as a jet which will be rigorously agitating the fluidized bed of a solid particles which are to be reduced. So, because of this agitation there will be kind of attrition amongst the particles, there will also be attrition between particles and in walls of the container, so the further reduction of the particle takes place.

Some reduction may occur when particles strike or rub against the walls of the confining chamber but most of the reaction is caused by interparticle attrition only. Internal classification keeps the larger particles in the mill until they are reduced to desired size. Suspending gas is usually compressed air or superheated steam admitted at 7 atm through energizing nozzles.

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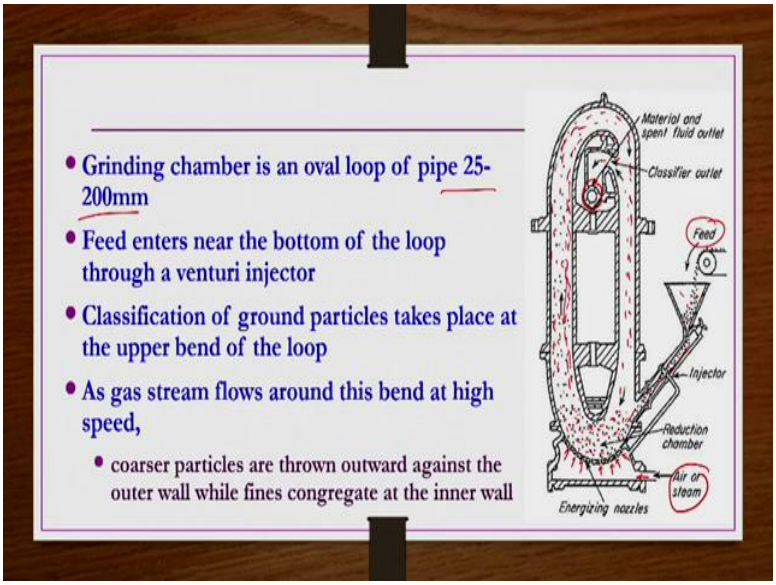

So, we see now a schematic of a fluidizing energy mill. So, here we have a kind of elliptical fluidizing energy mill like kind of thing. What happens here? We have a kind of a tube kind of thing on the tube is having between size 25 to 200 mm in general. So, whatever the feed that we have, that passes through this feed container from here and there is a kind of a venturi injector here so that feed flow rate can be controlled that has to be passed through this fluidizing energy medium. So air or steam is coming from here.

Here we can see there are kind of nozzles. These nozzles are known as a kind of energizing nozzles which provide higher speed for this the air or the fluidizing medium that is coming in. So, moment they come they come at a very high speed as a as a kind of Jet. So, whatever, the

particle coming down from the feeder from here so those particles will undergo some kind of reduction here.

So primarily this reduction is because of the attrition between the particles and in that attrition is causing because of the fluidization caused by this high energy or jet, gas streams coming as a kind of jets here. So, the primary reduction takes place in this area. So that is reason this the chamber you know whatever this chamber is that is known as the reduction chamber. Primary reduction takes place in this reduction chamber.

So the particles you know; the air stream flows like this and comes down like this it makes a kind of circulation within the equipment like this. But at the top we have a kind of classifier outlet as well so because of this one you know material and spend fluid outlet is taken out from here. Classifier outlet what it does, it separates the particles into the undersized and oversize. Undersized particles are taken to the classifier or cyclone separator from their and cyclone separator the particles are collected in a bag collector.

Whereas the oversize particles are coming down again here and then they will continuously undergo kind of a size reduction until the average size of the particle becomes less than the required size. Okay. So this is the schematic of the fluid energy mill and this is in general kind of operating processor. So, it consists of grinding chamber which is an oval loop of pipe 25 to 200 mm in general. This oval loop pipe is having 25 to 200 mm size. Feed enters near the bottom of the loop through a venturi injector. Classification of ground particle takes place at the upper bend of the loop.

Gas stream flows around this bend at high speed from the bottom. Coarser particles are thrown out word against the outer wall while fines congregate at the inner walls. Okay, so fines are, which are passing closer to the inner walls they will be coming towards the classifier and the required separation takes place whereas the coarser particles are in general moving towards the outer wall and then they will be coming back for a kind of a further reduction along with the fluid in a kind of oval path because this chamber is in a kind of oval shape.

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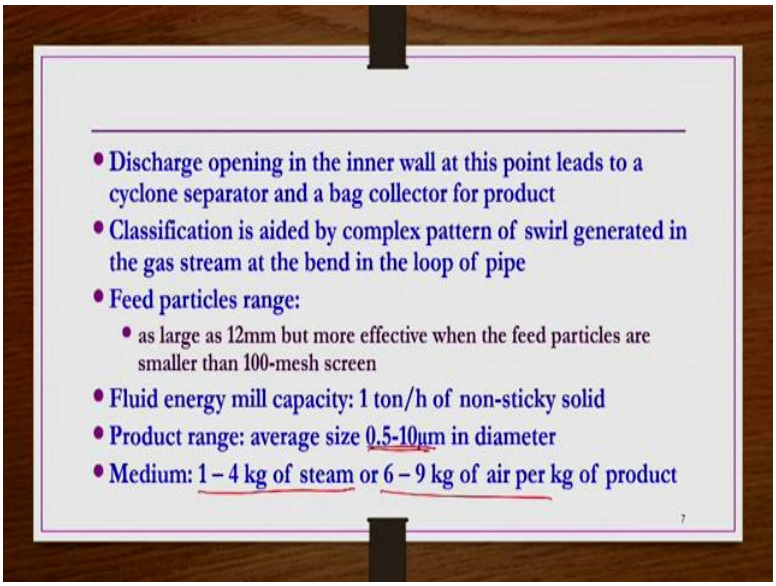

Discharge opening in inner wall at this point leads to a cyclone separator and a bag collector for product as explained. Classification is aided by complex pattern of swirl generated in the gas stream at the bend in the loop of pipe. Feed particles range, it can handle as large as 12 mm particles but it has been found that fluid energy mill works effectively, feed particle size is smaller than 100 mesh screen. However, it can also handle the particles up to 12 mm size large as well.

Fluid energy mill capacity is 1 ton/h of non-sticky solid in general and then product range it can be ranging between 0.5 to 10 microns in diameter. So, we can see the degree of attrition that is causing among the particles because of the fluidizing medium coming as a kind of a gas stream, coming as a kind of jet. Okay so we can see that you know almost up to, the particles up to 12 mm are also being reduced to size of a 0.5 to 10 Micron size so such high is the attrition in this kind of fluid energy because of the high speed jet that is circulating within the grinding chamber.

The medium that is in general used for this fluidizing these solid particles which are to be crushed are in general 1 to 4 kg of steam or 6 to 9 kg of air per kg of the product. This is about the fluid energy mill.

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So, now we go to the agitated mills. Agitated mills are a kind of small batch non-rotating mills containing solid grinding medium. Grinding medium in general consists of a balls, solid elements such as balls, pellets or the sand grains. These mills are in general vertical vessels having capacity 4 to 1200 litres filled with a liquid in which the grinding medium is suspended, the liquid has to be non-reactive and non-corrosive.

The charge is agitated with multi-armed impellers, whatever the feed along with the grinding medium that that you know along with the liquid that is no agitated with multi-armed impeller so that you know enough agitation takes place. There is also reciprocating central column which vibrate the vessel contents at about 20 hertz. Concentrated feed slurry is admitted at the top and product along with some liquid is withdrawn through a screen at the bottom. And this agitated mills are in general found to be useful in producing particles less than 1-micron size.

Next, colloidal mills, colloid mills are in general a kind of a homogenizers rather than size reduction equipment they will be doing a kind of homogenization in a what happens in general you know particles are agglomerated are clustered loosely in general. Lightly clustered particles are agglomerated particles are there, there may be forming a kind of bigger lumps. So, those kind of particles maybe in a disintegrated and a kind of homogenization may take place. In this colloidal mill what we have in a kind of a stationary casing would be there and then there will be kind of a rotating disc would be there.

So this, the gap between this casing and then disc case is in general very-very small very small like you know it is in between 1 to 25 microns. So the feed comes in between trap between this thing that will be homogenized into a kind of an individual of particles. Whatever the clusters are there they will be disintegrated and kind of homogenization takes place. That is the basic principle of this colloid mills.

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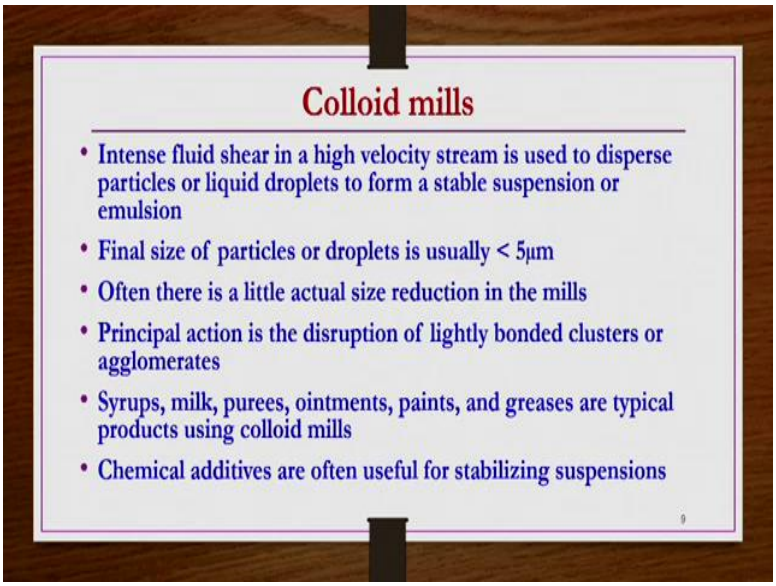

Intense fluid share in a high velocity stream is used to disperse particles or liquid droplets to form stable suspension or emulsions. In general, this kind of mills are used for you know pharmaceuticals like preparing the suspensions etcetera. Final size of particles or droplets is usually less than 5 microns. Often there is a little actual size reduction in the mills as I mention, there is you know kind of almost negligible kind of reduction there in the particle size but there is a kind of disintegration of clusters or the you know agglomerates.

Principal action in the disruption of lightly bonded clusters or agglomerates that is the principle action that is taking place in colloid mills that is there will be disrupting the lightly bonded clusters or agglomeraters by so that by disintegration a kind of you know a homogenization of the suspension takes place. In general syrups, milk, purees, ointments, paints and greases are typical products using colloidal mills. The chemical additives are often useful for stabilizing suspensions as well.

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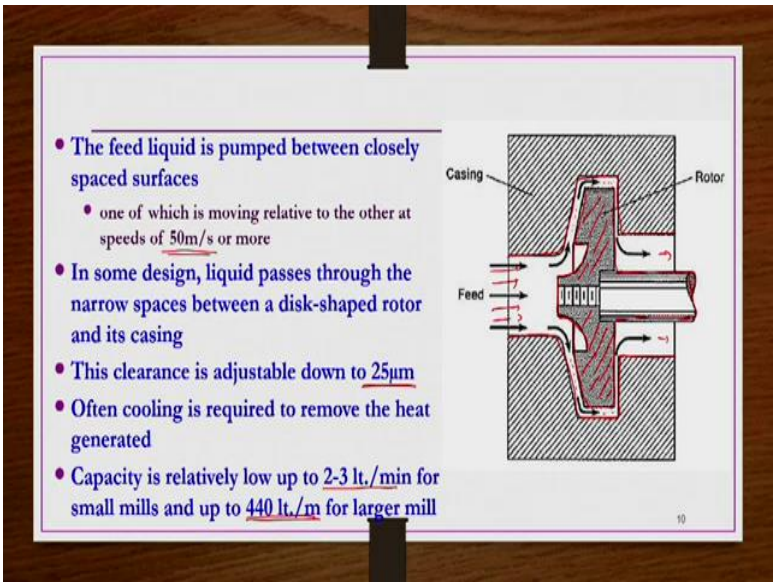

So typical schematic if you see we have a kind of casing like this. Casing that is for a colloid mill like this and there is a rotor, with a kind of you know disc kind of shapes, some different types of disc are possible. These discs are in general connected to a kind of rotor which rotates. It rotates in this direction which are we are we need to rotate. It can be rotated in either of the direction but in general they are rotated in one single direction.

So, this is the one that this kind of thing that is connected to the rotor is rotating. Whatever the feed that is there that comes in here from here like this and then trapped between the narrow space, between these two casing and rotor. So, whatever the feed that is coming here that will be disrupted and formed a kind of individual particles having kind of homogenization or individual droplets.

If not in individual kind of small droplets will form. Smaller particles will without any kind of agglomeration or clustering kind of thing. So, whatever the cluster agglomerated kind of particles are they will be broken down when they come between these casing and rotor because when it rotates the particles will be disrupted and then product is collected as a kind of homogenizer products. This is a kind of very much useful mill in general of a ray kind of suspension, purees, ointments, greases etcetera.

So, the feed liquid is pumped between closely spaced surfaces. One of which is moving relative to the other one at speeds as much as high 50 m/s or more, so the speed is very much high in general, because that is required because this particles though they are clustered or

agglomerated. The size is not very high maybe 20, 20 to 30microns something like that and then you need to do the disruption of the cluster so that we can have a kind of particles or droplet less than 5micron or something like that.

So, you need to have a kind of very high speed in this case and because this the surfaces are almost touching to each other, the gap is very much closed narrow, so what happens a kind of heat generation will also take place because of the viscous dissipation and then that heat has to be transferred or by applying the coolant that heat has to be removed otherwise the product properties may be affected because this product in general this purees, syrup, ointments etcetera are heat sensitive products.

In some design liquid passes through the narrow spaces between a disc shaped rotor and its casing, the clearance is adjustable down to 25 microns. The gap between this casing and then rotor can be reduced to as smaller as 25 microns that is they are almost touching to each other. Often cooling is required to remove the heat generated in this kind of colloid mills. The capacity in general very low and there are two types of mills are there based on the capacity.

Small Mills are having 2 to 3 L/min capacity whereas larger mills may have a 440 L/min capacity. So, depending on the capacity of these mills they can be small mills they can be larger mills. Large mills can handle as much as 440 L/min that is a very big capacity, especially considering the type of product we are handling in this colloid mills.

So, that is about the ultrafine grinder having you know for dry and then wet products. For dry products you know we have to use the hammer mills with internal classification or external classification or the fluid energy medium for the wet grinding under the ultra1fine grinding conditions you how to use the agitated mills something like colloidal mills etcetera.

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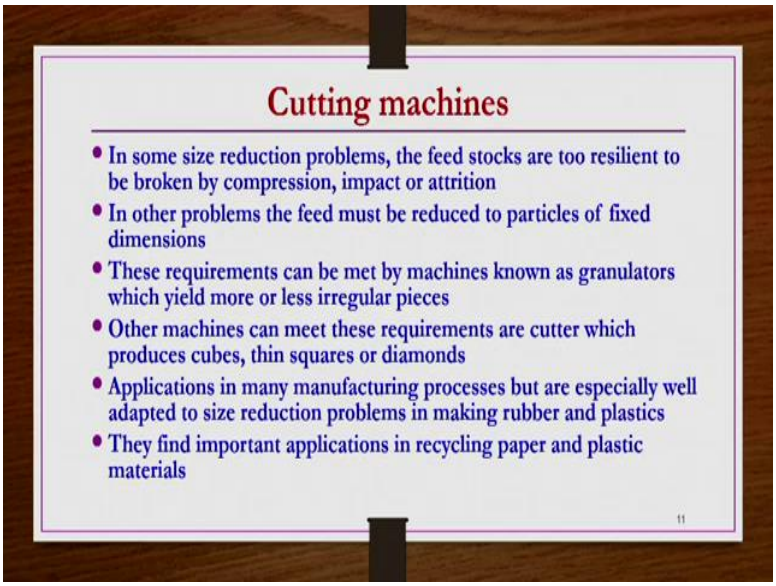

Now we see some details about the cutting machines. Cutting machines in general, in some size reduction problems what happens the feed stocks are to resilient to be broken by compression, impact or attrition that is quite possible depending on the nature of the feed but often we have such kind of feed stocks while undergoing size reduction operation. So, they are very resilient to be size reduced by the compression, impact or attrition.

Sometimes, you know feed must be reduced to particles of fixed dimensions that is also required depending on the situation in some problems you need to have the feed of define at fixed dimensions. These requirements can be made by machines known as the granulators which yield more or less irregular pieces but the same requirement can be met using the machines called as the cutters which produce regular shape of particles cubes, thin squares or diamonds.

Whereas the granulator they yield a product of more or less kind of irregular shapes. If you use the cutters for the same operations you can get a kind of a regular shape of products like cubes, thin squares or diamonds. These cutting machines can find applications in many manufacturing processes but are especially well adapted to size reduction problems in making rubber and plastics. They are also finding applications in recycling paper and plastic materials as well.

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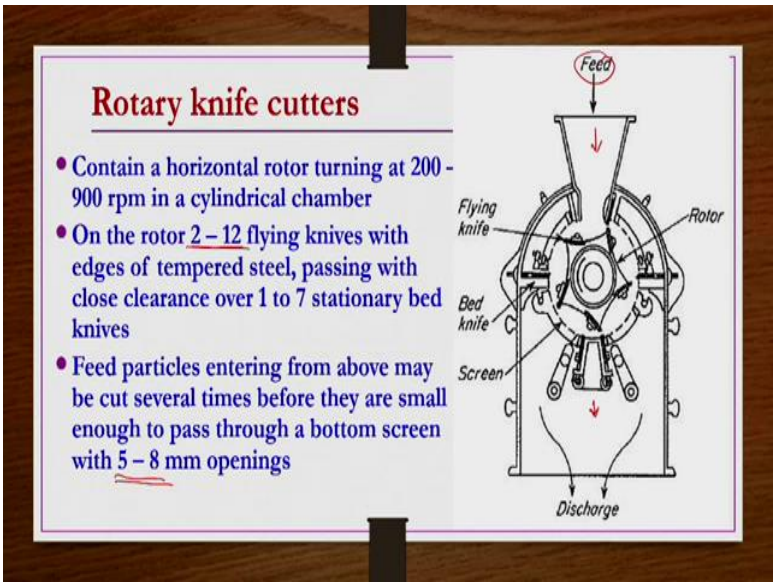

So, now we see equipment available for cutting machine. So, let us take an example of rotary knife cutters. So, here what we have, we have a horizontal rotor here as shown here, there is a horizontal rotor here like this which may be carrying several flying knives like this. These knives are in general flying kind of thing. So, whatever the feed that is coming in from hear that that will be undergoing a kind of size reduction by this flying machines so this this size reduction this cutting is taking place until and to a kind of a desired size.

So, they will be continuously undergoing a kind of a size reduction because there is a screen at the bottom at the discharge. So, whatever these size specified size is made by the size reduction those particles or undersized particles are taken to the discharge whereas the oversized particles you know they will be inside the machine only and then there will be further undergoing size reduction by this is flying knives. So that is the basic principle in this Rotary Knives.

So here what we have seen it contain a horizontal rotor turning at 200 to 900 rpm in a cylindrical chamber. On this rotor there are 2 to 12 flying knives with edges tempered steel, passing with close clearance over 1 to 7 stationary bed knives. Feed particles entering from above may be cut several times before they are small enough to pass through a bottom screen with 5 to 8 mm openings.

So this particles whatever coming from the top they will be undergoing cutting several times until the size becomes you know 5 to 8 mm size and then the particles smaller than 5 to 8 mm size they will be collected through the discharge at the bottom whereas the particles larger than

the 5 to 8 mm they will be retained inside the machine and then they will be further undergoing a kind of a cutting action by this flying knives. So that is a Rotary knife cutter.

So there are different types of you know Cutters. Cutting machines are also available industrially. So those details can be found in a kind of book by the Colson and Richardson sec you know Chemical Engineering Series second volume. There are several types of you know equipment are available under each category of crushes, grinders, ultrafine grinders and cutters.

They have also discussed different types of industrial equipment as well. So we have seen some of them. If the readers are interested may go through that book for more and more details about different types of industrial size reduction machines. Readers may also go through another book by Brown et. al. That is Unit Operations by Brown et al; they have also discussed the several types of industrial you know size reduction machines available.

So, having seen some basic details about the size reduction equipment under the category of crushes, under the category of grinders, under the category of ultrafine grinders, and under the category of cutting mesh, it is important to find out you know what is the criteria for the size reduction or the selection of what is the criteria for selection of size reduction equipment? Which equipment should be used for a given application? That is again a kind of important so we see those details now.

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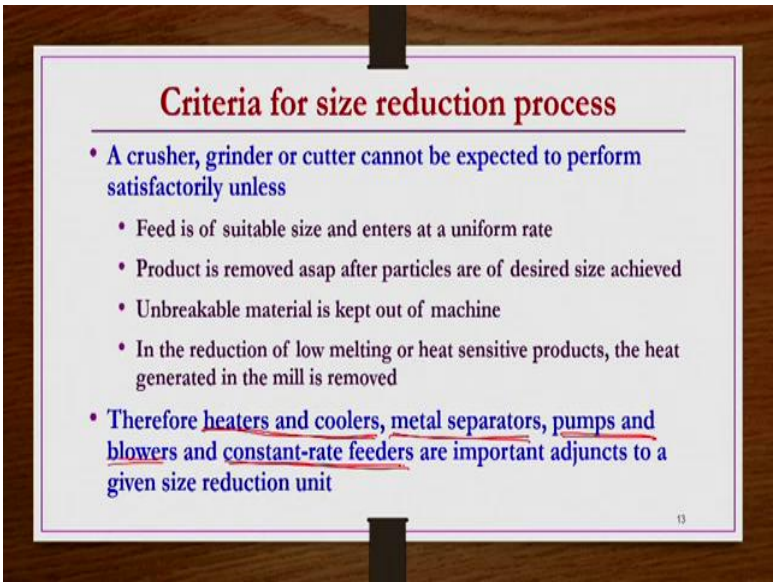

Criteria for size reduction process, one must know that the crusher, grinder or cutter cannot be expected to perform satisfactory unless the feed is of suitable size and enters at a uniform rate.

As we have seen just now if like in fluid energy mill can handle particle as larger as you know 12 mm but if the particles are smaller it will be more effective. But if you have a particles like 20 mm or 50 mm that cannot handle. So, the feed should also be suitable size for a given operation.

So that that is very much essential for a given applications. Okay. So, similarly if you have a Jaw crushers etcetera that handles big lumps directly coming from the mines but in the same equipment if we use for the fine particles or having size 1 mm or less than 1 mm something like that they will be not effectively doing this size reduction operation. So one must be very specific about the feed size and then accordingly one has to choose a kind of equipment required for the size reduction.

Sometimes the product size also matters depending on the - what type of product what size of the product that you need then you may choose a kind of equipment. So, there maybe equipment which may be handling a given feed, let us say feed it is having 30 mm size you may find there are 2-3 types of equipment that can handle but if you see the products some of that equipment maybe producing 1 mm or 2 mm particle whereas some of that same equipment which can handle 30 or 40 mm particle feed they may produce the particles of 0.001 mm something like that or some micron size particles they can produce.

Sometimes it also becomes that the not only feed size the required product size also makes a kind of essential criteria for selection of this size reduction equipment. Also feed must be entering at a uniform rate that is another important thing if you wanted to have a kind of satisfactory crushing. Product should be removed as soon as possible after particles are of desired size are achieved. So you cannot retain particles you know, let us say you need have a particles of average size 1 mm from the feed size of average 100 mm.

So, once the particle size you realize that they are almost like in a 1 mm particle size has they have been reduced to 1 mm particle size it is better to remove the product as soon as possible otherwise those particles may further undergo kind of size reduction and then the size of the particles maybe become much smaller than one required 1 mm or in other cases it may be like it may not be doing the further size reduction beyond certain product size of 1 mm or 0.5 mm or something like that.

Under search condition if you are not removing the product you may be wasting the energy further. So as we already discussed energy is a kind of important factor here so that way also

in terms of energy saving also it is better to remove the product as soon as the desired size is achieved. Then it is always advisable to keep the machine out of unbreakable material. There are some types of attrition mills we have seen where you know one of the disc may be mounted, spring mounted so that to avoid breakage because of the unbreakable material being trapped between the disc.

But such provision may not be available for all type of size reduction equipment. So it is always advisable to have a feed which can be broken. So, any unbrokable or unbreakable material is there that must be kept out of the machine so the feed has to be carefully checked so that to avoid any kind of a unbreakable material should not be present in the feed. In the reduction of low melting or heat sensitive products the heat generated in the mill must be removed, otherwise the product properties may be changing, like in a kind of a colloid mills etcetera.

Okay. So when you maintain this kind of conditions then only you can expect a kind of size reduction equip equipment is performing satisfactorily. Otherwise you may not be satisfied with the performance of the equipment as well the power consumption may also be higher and then capacity may also be not significantly high as you expected. So, it is necessary to keep this point in mind before selection of the size reduction equipment and then the saving of the energy as well.

Therefore, what we understand from these point, the heaters and coolers, metals separators, pumps and blowers and constant-rate feeders are important adjuncts to a given size reduction unit. So, wherever the heaters and coolers like you know is any heat removal or heat addition is required so then we may need heaters and coolers. If you wanted to maintain the feed free from unbreakable material such as metals etcetera.

So metals separators are also found to be kind of a good adjunct for this size reduction equipment and then definitely pumps and blowers we have seen already several types of pumps and blowers are involved in kind of size reduction equipment. Also constant-rate feeders are also kind of very much essential in order to have this machines performing satisfactorily.

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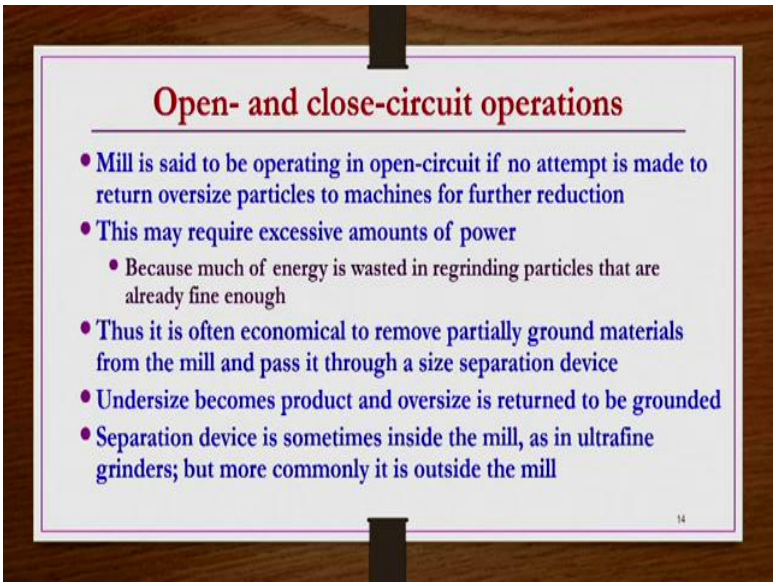

Then the mode of operation open and closed circuit operation. If the material if you feed material have taken in mill and then you have done a kind of size reduction and then whatever the material that is coming as a kind of product you directly take out without being you know separating them as a oversize, undersize then you can say that a kind of open circuit operation. That is you do not product whatever is there you are not classifying into the different sizes and then you are not sending back the oversize material to the mill for further reduction then you can say that is a kind of open circuit operation.

But in general it is most of the mills run in a closed circuit mills where the power savings is also kind of important factor. So, what you do you know you do a kind of size reduction equipment then you classify the product into the oversize and undersize. Undersize you may be taking as a product oversize may be sending back to the mill for other reduction. So the circuit is closing by the feedback kind of thing or returning the oversize material to the crushers.

So, that way those kind of mills you know we called as a kind of closed circuit operations. That is the only basic difference between the open and closed circuit operation. In the open circuit operation there is no returning of a some of the product to the crushers for the further reduction whereas in closed circuit operation there is a certain amount of material from the product which is oversized is sent back to the crusher or mills for the size reduction.

So that is happens in the closed circuit operation. So, a kind of recycling is there in the closed circuit operation whereas in the open circuit operation there is no recycle kind of operation. Now you see some of these details about them. Mill is said to be operating in open circuit if no

attempt is made to return oversized particles to machines for further reduction. So, if you are not making any attempt to return oversize particles to machine for further reduction then you can say such kind of mills are operating under open circuit conditions.

This may require excess amounts of power in general why because sometimes you know because of much of energy is wasted in grinding particles that already fine enough because what happens when you do a size reduction operation in a given mill or crushing equipment or any size reduction equipment. After a certain time of operation the satisfactory lead, product is no more or less of satisfactory size as per the equipment you know restrictions feed and product requirement.

So but then in such case if you are not separating the undersize you are unnecessarily wasting energy for the material which is already sufficiently fine enough. So, that way it is not going to be helpful anyway. So, it is often economical to remove partially ground material from the mill and pass it through a size separation device, undersize may be taken as product, oversize may be taken as a kind of return to the recycle to the size reduction chamber for the further size reduction.

This way you know what we can have one can save the energy as well as the specific size product size requirements can be maintained, if not entire exactly uniform the product size distribution maybe a very narrower in the case of a closed circuit operation but in the case of open circuit operations in the products as may be a broader. The distribution of the product may be a broader. Whereas in the closed circuit operation since the undersize are separated oversize are send back for the further reduction.

So the further reduction will take place and then more or less final product after the end of the operation we may have a kind of narrow product size distribution in closed circuit operations. Separation device is sometimes inside the mill but in general it is outside the mill. If you have a kind of, we have ultrafine grinders like something like hammer mills with internal classifications. So, like in such kind of arrangements we have the classifiers are the separation devices there. So, similarly the separation device may be inside the mill but that is not possible for all type of machines. Commonly this separation devices are outside the mill.

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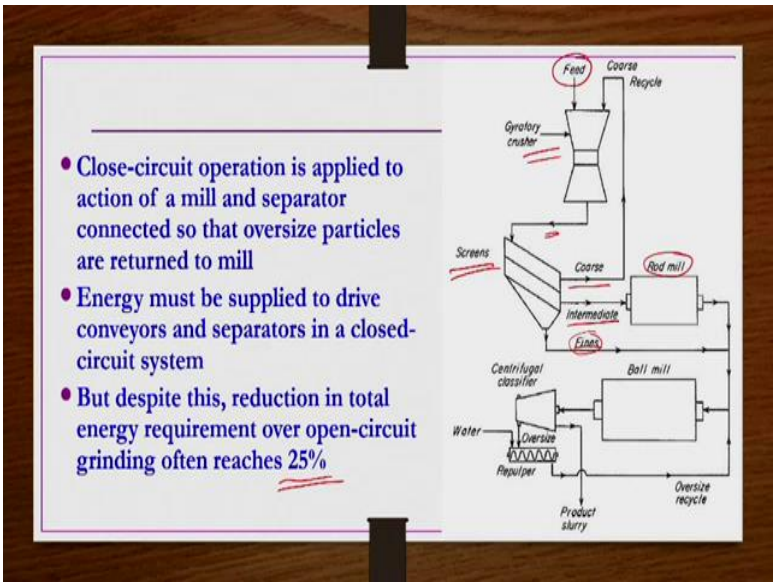

Now, schematically we see how a kind of a closed circuit operation taking place in size reduction mills. So, let us say we have a very big size of particles directly the material run away from the mines, whatever are there in big-big lumps like you know 1500 mm, 2000 mm size particles. Those can be taken into a gyratory crushers, for example, okay so they are the size separation is taking place. Okay whatever the product that is coming from this gyratory crushers that you can pass through screens. So here obviously you have a three types of you know products coarse, intermediate and then fines.

Usually many coarse will be there. Right you know in that coarse may be taken back and then recycle to the gyratory crushers again whereas the intermediate product may be taken to the next level in the rod mill. So there is in here in the rod mills the further reduction may be taking place. So the rod mill whatever the products are there, they can be separated is a kind of oversize and undersize kind of material.

So whatever the material that is coming from the ball mill if you are separating that is fine you can separate and then if you want oversize material you can send back here but let us say you do not have such kind of oversize or under separation here. So, whatever the product that you getting from here from the rod mill along with the fines that you obtained by the gyratory crushes all of them you can take to the ball mill. It is optional it is just a kind of example we are seeing. So, you can also have a kind of a screen or separating separation section after the rod mill also.

So here what we are taking the entire product from the rod mill as well as the fines from the gyratory crushers are taken to a ball mill here in the ball mills. From the ball mills what you can do, you can do a kind of separation where you know oversize undersized particles may be separated. Oversize particles may be sent back to the ball mill again for the further reduction. Undersize material can be taken as a kind of product as a kind of slurry. So this is how a kind of a general closed circuit operation takes place.

It is just a kind of typical arrangement to show a kind of you know crusher category equipment and then a kind of grinder category equipment along with in addition to that one there is a kind of separation by the centrifugal force is a kind of general representation but it is how it looks. As per the requirement of your product depending on the feed and then depending on the equipment that you have, depending on their capacitor etcetera1 one can arrange kind of this equipment size reduction in a such a way that you can operate in a kind of closed circuit mode and then save as much of energy as possible.

And then get a product as much narrow a particle size distribution as possible. That is the advantage for this particular you know closed circuit operations. So, close circuit operation is applied to action of a mill and separator connected to that oversize particles are returned to mill. Energy must be supplied to dry the conveyors and separators in a closed circuit operations or closed circuit systems. In general what happens in open circuit system there is no requirement of energy supplying to the conveyor or separator etcetera.

But here in the case of a closed circuit operations we may need to provide additional energy for this you know operating of this conveyors and separators. However, despite providing the energy sufficient energy for operating this additional things like you know conveyors and separators still you can make a kind of energy saving compared to the open circuit operation and that energy that energy saving is as much as high as 25%.

So despite of this additional energy supplied to conveyors and separators reduction in total energy requirement over open circuit grinding is often reaches up to 25%. So, despite having this additional energy requirement in the closed circuit operation still there is a kind of energy saving compared to open circuit operations and that energy saving can be as much as 25%.

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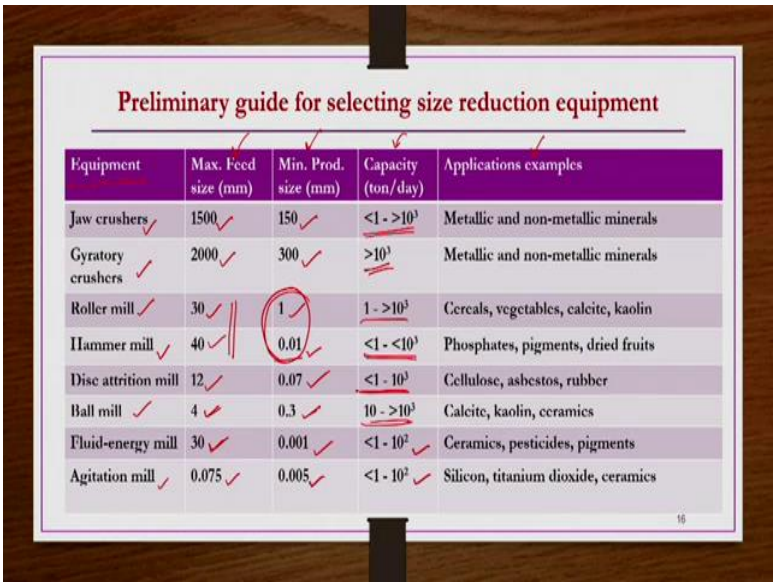

Now we see preliminary guide for selecting size reduction equipments. So we have seen different types of crushes, different types of grinders, different types of ultrafine grinders and then a few types of cutting machines as well we have seen and then we have also seen you know the mode of operation which is going to be feasible and then criteria for selection of the equipment etcetera or criteria for a proper satisfactory operation of this size reduction equipment.

But you need to have a kind of a preliminary guide in selecting this equipment as well, which equipment should be used? So first is the material, what type of material that are you choosing? That makes a difference and then what is the feed size? What is the average size of the feed? That also makes a difference in selection of this equipment. So that guide we see especially for those equipments we have studied in this last three lectures.

So here what we have? We have a table which gives details about the name of the equipment, what is the maximum feed size this equipment can handle and then what is the minimum product size that you can expect from this this kind of equipment and what is the capacity in tons per day and then where are the applications that you find for this kind of you know equipment.

So, first equipment that we have studied is Jaw Crushers. The maximum feed size it can handle up to 1500 mm and then minimum product size it can produce up to 150 mm. It can have the capacity, wide range of capacity less than 1 ton/day to almost 1000 tons/day it can handle wide

range of capacity and in applications in general we can find in any metallic and nonmetallic minerals industry.

Next one, we have Gyratory Crushers. It can handle maximum feed size as much as 2000 mm and then it can produce minimum products as much as the 300 mm. The capacity is in general very high more than 1000 tons/day. These are also fine applications in metallic and nonmetallic minerals. Then Roller Mills smooth and two roller mills we Roller mills we have seen. We have seen two types of Rolling Mills smooth and tooth roll roller mills.

So they can handle maximum feed size up to 30 mm and then they can produce products of minimum product size of 1mm, their capacities also very wide 1 to 1000 tons/day. Applications are in cereals, vegetables calcine calcite, kaolin, and etcetera. Then we have hammer Mill. They can handle particle size up to 40 mm whereas the minimum product size can be 0.01 mm.

Now, you can see the roller mill and then hammer mill the maximum feed size they can handle is almost close to each other 30 to 40 mm but you can see the product size minimum products size is very much different. Roller mill can produce product up to 1mm only, whereas the hammer mill can produce the product up to 0.01 because of the in addition to impact there is a kind of attrition also taking place in hammer mills.

So you need to have a product less than 1 mm or less than or close to the 0.1 or 0.01mm so though your the feed is of suitable range for the roller mill you have to go for a hammer mill because your product size is the finer than 1 mm or your product size requirement is finer than 1 mm or smaller than 1 mm. The capacity here again the capacity for hammer mill is very wide range less than 1 ton per day to 1000 tons per day it can handle.

The applications you find in general in phosphates, pigments, dried fruits etcetera. Then we had a Disc Attrition Mill which can handle the feed size maximum feed size of 12 mm and then it can produce particle size of 0.07 mm. The capacity is again less than 1000 tons per day. The material applications in general where we use this disc attrition mills are cellulose, asbestos, rubber, etcetera.

Then we have a Ball mill where the different types of balls have been taken as a kind of grinding medium. So it can handle the feed size maximum feed size of 4 mm but it can produce the product size up to 0.3 mm only. The capacity varies is in between 10 to 2000 tons pre day. The

material it handles in general calcite, kaolin, ceramics, etcetera. Then fluid energy mill it can handle up to 30 mm and then it can produce product up to 0.001 size.

Okay that is almost 1 micron size it can produce but however, just now we have seen if the feed size is less than 12 mm or something like that then it performs very much better. The capacity is in general less than 1 ton per day to almost 100 tons per day. This fluid energy mills finding several applications in ceramics, pesticides and pigments industries. Then Agitation mill just now we have seen which handles maximum feed size is 0.075 mm and then minimum product size in in general 0.005 mm.

The capacity varies in between less than 1 ton per day and 100 tons per day. Applications it finds in Silicon, Titanium oxide and ceramics kind of material. So this is about the size reduction equipment the different types of equipment we categorize like crushers, grinders, ultrafine grinders and cutters or cutting machines we have seen. Under each category specific type of applications we have seen.

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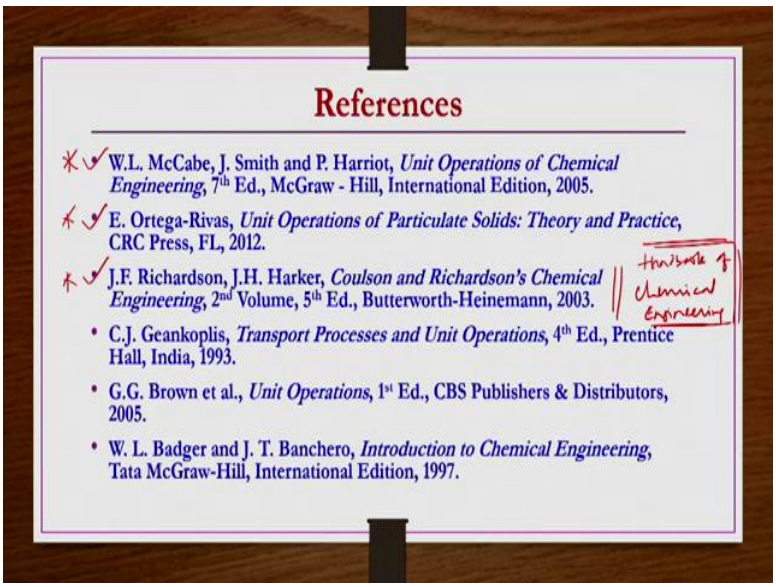

So, the material that has been discussed in these three different lectures covering variety of size reduction equipment have been collected from this reference books. McCabe, Smith and Harriot that is Unit Operations of Chemical Engineering, then another book Unit Operations of particulate solids theory and practice by Ortega-Rivas, then Coulson and Richardson's chemical engineering series second volume by Richardson and Harker, then transport processes and unit operations by C.J. Geankoplis, then unit operations by Brown et al and Introduction to chemical engineering by Badger and Banchero.

Primarily details that have been discussed under the size reduction equipment a have been taken from the three books. Majority of the information is taken from the McCabe and Smith and then Richardson and Harker. Some details of figures are also been taken from this Ortega-Rivas. But however for additional you know information about different types of industrial size reduction equipment one can go through Richardson and Harker that is Coulson and Richardson's chemical engineering second volume.

Also one can go through the handbook of chemical engineering it is Paris Handbook of Chemical Engineering. If you go through this book chapter number 21, you can have a wide variety of size reduction equipment especially used for industrial applications. Thank you.