Mechanical Unit Operations
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Lecture No. 9
Equipment for Size Reduction – Grinders

Welcome to the MOOCs course mechanical unit operations. We are discussing equipment for size reduction in the previous lecture, we have seen one particular type of equipment that is crushers. The equipment for size reduction. There are several types of equipment are there - crushers, grinders, ultrafine grinders, and cutting machines. So, in previous lectures, we have seen crushers which are primarily used to for course reduction. This particular lecture the title of this lecture is equipment for size reduction where we will be discussing about the grinders which are a kind of intermediate and fine reduction which are used for the kind of intermediate and fine reductions.

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In general, grinders are intermediate duty size reduction equipment. The feed for the grinders is in generally the product that we get from the crushers. The crushers are a kind of course reduction equipment from those crushers whatever we get the product that product we take as a kind of feeding in kind of a grinders to do further size reduction.

There are several types of commercial grinders are available. We see some of them in this particular lecture. So, let us say we have a Hammer mills and impactors, rolling compression machines. We have attrition mills and also we have tumbling mills. So, we are going to see a few details of all of all these four types of commercial grinders. Let us start with the hammer mills.

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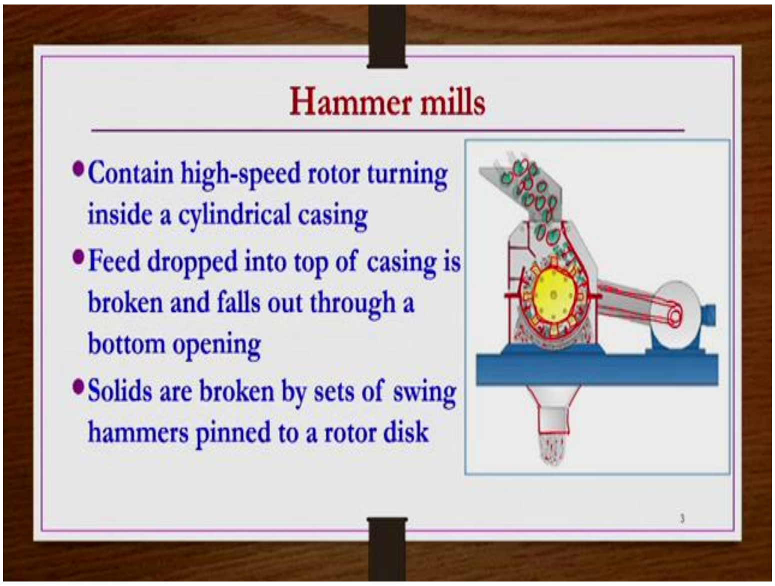

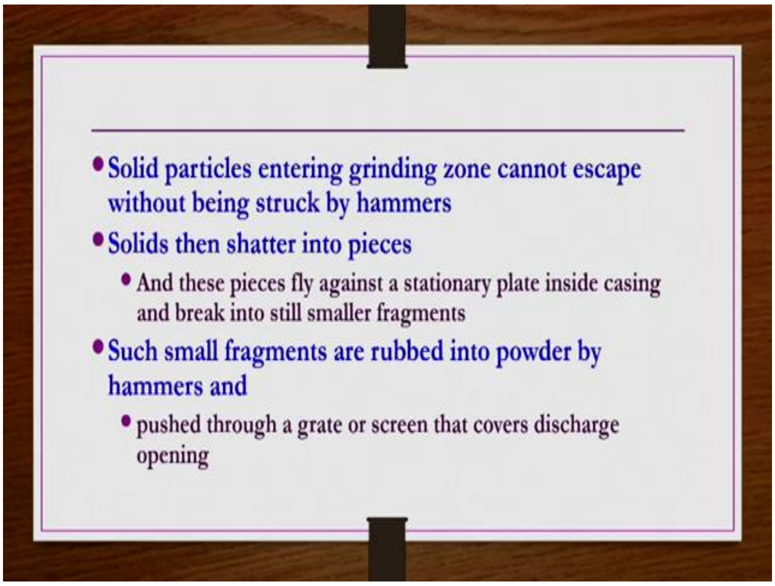

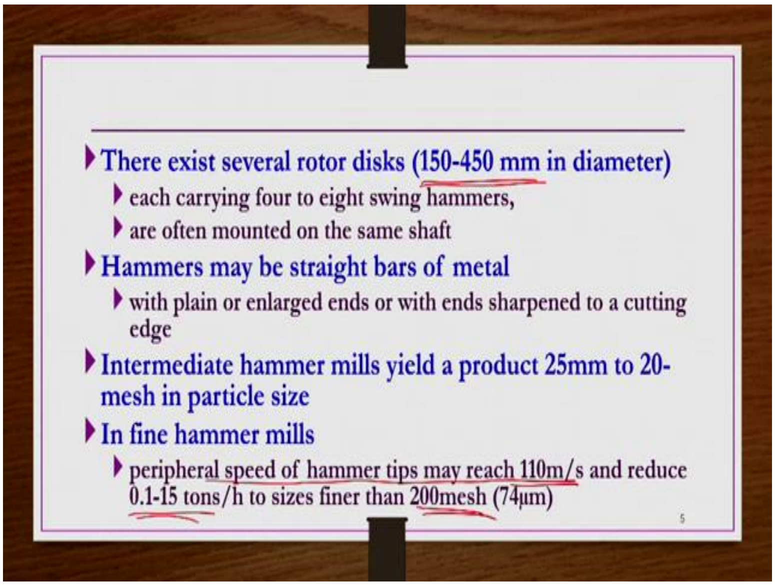

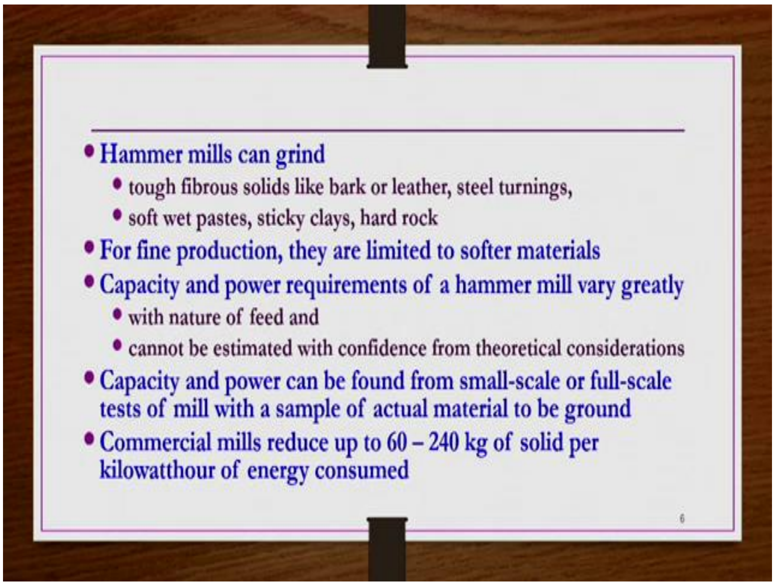

Hammer mills are in general what looks like this as shown in the schematic. Here what we have a high-speed rotor is there in general like you know they have shown here. In a kind of cylindrical cylindrical casing are are shown here like this. So, these rotor speed rotates at a high speeds in general so it may have a four to eight swinging hammers pinned on them. As shown here these hammers as swinging. There may be more than one rotor. In general, there exist several rotors like this but all of them are connected to one particular shaft.

Only one single on this onto the same shaft like the here. Here we have shown only one rotor and then connected to one particular shaft. Even if you have a several rotors like this you know all those rotors are connected to one single same shaft. So, when these rotors rotate you know the hammers pin onto them they will swing. They will swing and then show impacting action. So, whatever the feed material that comes in. And then trapped between this casing and then hammer meals you know that will be broken moment we start rotating these high-speed rotors.

When we the rotors rotates, the hammers spin on to them they start swinging and then they will show you kind of impact kind of force on this particle those particles will be broken down and then size reduction will take place. Sometimes these broken particles will fly towards the casings like this and then they will further be go undergoing some kind of one size reduction when they have a kind of impact on these casings also. And what happens these swings swinging hammers will also have a kind of swing in such a way that there will be a kind of attrition also taking place.

So, in this hammer mills the size reduction occurs by two types of forces. One kind of one is the impact kind of force another one is a kind of attrition kind of force. And then whatever the size reduction material that is collected over here that will be pushed through a grate or a screen which is connected at the bottom. So, whatever the let us say you have you you need to have a kind of particles you know passing through two hundred mesh something like that. So then you can attach.

You can have a screen of two hundred meshes. And then the materials finer than the two mesh size they will be taken out collected out as a kind of product whereas the other products will be retained inside the casing and then they will further be undergoing a kind of a size reduction. So that is the basic principle. See one by one of the details as well. So this is what the basic principle in the hammer mills any of the hammer is that we take. That is feed dropped into top of casing is broken and falls out through a bottom opening here as shown here. Solids are broken by a sets of swinging hammers pinned to a rotor disk.

We have a rotor disk there are there may be several rotor disks. The solid particles entering the grinding zone cannot escape without being struck by the hammers because you know there are several types of several numbers of rotors are existing and then each rotor is pinned with four to eight swinging hammers so it is not possible that particle to escape it without being hammered by a swinging hammer. So whatever the feed that is enters that will definitely be struck by the hammers because of so many rotors and then each rotor is having so many swinging hammers. So, there is a definitely the size reduction would be degree of size reduction would definitely be higher in this particular case.

Whatever the solids are there once they being struck by the hammers they will be shattered into small pieces. And these these pieces as I mentioned fly against a stationary plate inside the casing and then break into still smaller fragments. So, they will further also be broken into a smaller pieces once they interact with the stationary plate inside the casing. These small fragments are further rubbed into powder by hammers. These hammers swinging hammers designed in such a way that not only the swinging action is taking place but also there is a kind of rubbing action kind of thing is there. So because of that one smaller small parts already broken particle will further undergo kind of a rubbing action.

So this powder then pushed through a grate or screen that covers discharge opening. So, that opening may be having some kind of screen which as per the requirement of the product if you need a very fine product then you can have a kind of two hundred mesh screens at the bottom at the discharge point so that you know finer particle, particles smaller than 75 or 74 microns can be taken away as a kind of product. If you need a kind of a product of certain certain like you know, 60 mesh screen then such kind of screens has to be used. So according to applications one can use these screens different types of screens and then one can get the products both intermediate and fines size but as per the requirement.

As I mentioned there exist several rotor disk. (Us) Usually, they have a diameter 150 to 450 mm. And then each rotor may be carrying four to eight swinging hammers and are often mounted on the same shaft whatever the rotors are there. There are several number of rotors that they will be mounted on to the same shaft. Hammers in general maybe straight bars of metal in general having plain or enlarged ends or with ends sharpened to a cutting edge. Intermediate hammer mills yield a product 25 mm size to 20 mesh size in particle size. Or in other words the particle size distribution that we get from intermediate hammer mill is in general varying between 25 mm to 20 mesh opening size.

On the other hand, in fine hammer mills the peripheral speed of hammers tips may reach so high like a 110 meters per second. And that can reduce the material 0.1 to 15 tons per hour capacity the capacity of such a fine hammer mill is in between 0.1 to 15 tons per hour and they can produce a finer material of the size 200 mesh or even smaller also possible. So, if you have a kind of finer mesh so then you can have the furthers finer mesh in place of 200 and then you can get a kind of product like up to 200 mesh. So, it is in general peripheral speed of hammer tips may reach as high as 110 meters per second and reduce the feed at 0.1 to 15 tons per hour.

So that to get a finer sized product up to 200 mesh size that is up to 74 microns smaller particle you can get by this fine hammer mills. So that is the reason this hammer mills, in general, are categorized as intermediate or medium or fine reduction. Whereas the crushers are classified are kind of used to for course reduction. These mills these grinders, in general, are kind of intermediate and fine mills, fine reduction. Hammer mills have a advantage of grinding both the tough and then soft material so they can grind tough fibrous solids like bark or leathers, steel turnings etcetera. They can also handle soft wet paste, sticky clays, hard rock etcetera.

For fine production they are limited to softer materials only. In general, if you are using the softer material then only you can get the finer production by using hammer mills. But if you are using harder material then you may be ending up primarily with the intermediate material. The capacity and power requirements of a hammer mill vary greatly with the nature of the feed and this capacity and power requirements cannot be measured with the confidence from theoretical considerations. So how to get this capacity and then power requirement for this kind of hammer mills one has to do the real life experiments with a kind of you know small setup or a kind of a full scale test by using the actual material that is to be grounded.

So, that is capacity and power requirement for a hammer mill should be found from small scale our full scale test of a mill with a sample of actual material to be grounded. So, you cannot rely on the power requirement and capacity calculations theoretically that we have seen previously in the one of the previous lecture whatever the crushing loss that you use in order to get the power requirements. So, the power requirement obtained by those crushing laws may not be reliable in the case of hammer mills. So for hammer mills one has to go for a capacity and power requirement calculations by using a small scale our full scale hammer mills with the same sample that is going to be actually grounded in real life applications. In general, commercial hammer mills reduce up to 60 to 240 kg of solids per kilowatt hour of energy consumed.

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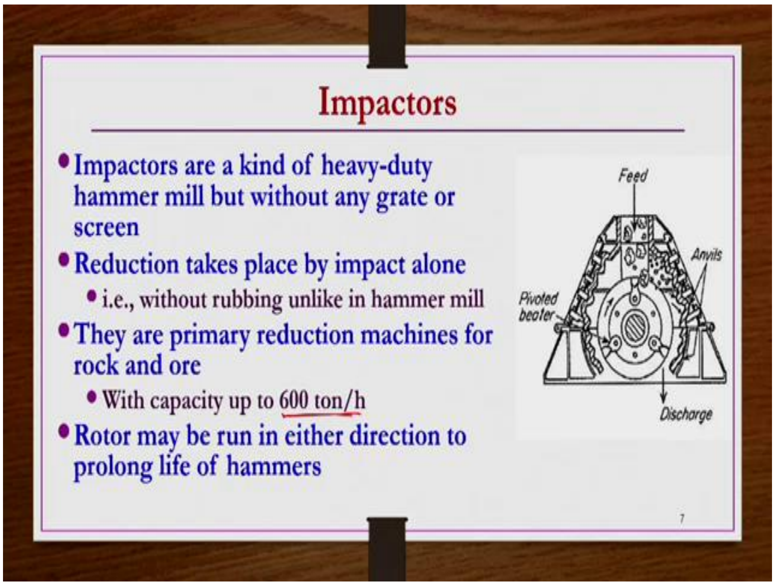

So next is the impactors. So impactors is a kind of heavy duty hammer mills only as we have shown here. So the working principle is exactly same. But there are only two changes, here at the discharge we do not have any grate or screens so that to control the output size product, whatever it comes size after the size reduction is done that we directly take out. And then there is only hammering kind of action. The design of the hammers or the motion of the hammers for the size reduction in such a way that here we get the only impact kind of forces. We do not get any kind of rubbing kind of forces. But these are good for high capacity they are in general heavy duty hammer mills kind of thing.

If we want to say in single words impactors are a kind of heavy duty hammer mill but without any grate or screen of the discharge. And then reduction takes place by impact only without any attrition or rubbing kind of action as we have seen in hammer mills because the hammers are connected to the rotor in such a way that they can show, they can have only a kind of impact motion impact force only they can exert they cannot exert any kind of rubbing motion they cannot exert any rubbing action. They are primary reduction machines for rock and ore because they are handle in a large capacity, capacity up to 600 ton per hour.

In general, what we are seen in jaw crushers and gyratory crushers the capacity is approximately a thousand tons per day. So, in the course reduction equipment like crushers etcetera, we have in general a thousand tonnes per day kind of capacity whereas these impactors are further higher capacity we can see here just an hour one can handle up to 600 tons. That is the reason these materials these impactors are nothing but a kind of heavy duty hammer mills. The duty is heavy so they can handle large amount of material.

And then further rotors are placed such a way that they can run in both the direction either of the direction so that to prolong the life of the hammer because when they are these hammering these swinging hammers are you know showing impact on a kind of material they are also being receiving some kind of force back on on on the surface of the hammers also. So, that is way it is better to have a kind of prolong life of hammers and then in order to have the prolong life of hammers the rotors designed or connected such a way that they can run in either of the directions.

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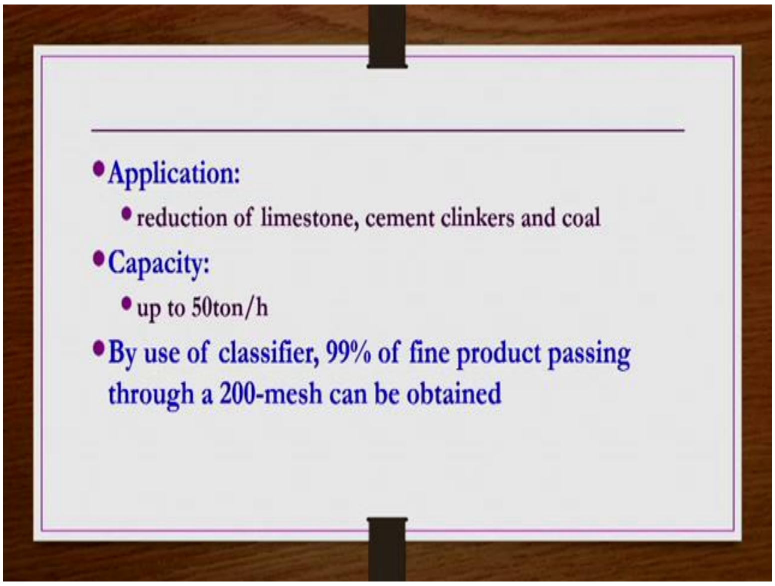

Next one is roller mills. Roller Mills basically, in general, we have a kind of two rollers both of them rotating or one of them rotating and there will be a kind of ring kind of structure. So the material that is trapped between because of the rolling action of these cylinders the material size reduction will takes place. So, that is the basic principle in the roller mills so roller mills in generally, consist of a cylindrical rollers and a ring. So, the cylindrical rollers maybe both of them may be rotating or maybe one of them may be rotating either one maybe stationary either of the operations are possible.

When the material that is to be undergo size reduction trapped between these rollers that will be crushed because of the rotation of the cylinder, say that one cylinder of both the cylinder rotating. So that when the size reduction takes place. So that is the basic principle of these roller mills. They consist cylindrical rollers and the stationary ring. Solids are caught and crushed between these rollers and stationary ring in general. Rollers are driven at moderate speeds in a circular path. Plows lift the solid lumps from the floor of the mill and direct them between the ring and rolls for the required size reduction for the required size reduction.

Product is in generals swept out of the mill by a stream of air to a classifier separator. From the separator oversized particles are returned to mill for further reductions so that you know you can control on the product size any oversized material that is there that is taken back to the mill after undergoing this classifier operation. The application of roller mills in general we find in a reduction of limestone, cement clinkers and coal. The capacity of these roller mills in general up to 50 tons per hour.

And then when one uses the classifier, the fine product the fine product that you get out of that fine product you can expect to have 99% of the product passing through 200 mesh screens so such is the guarantee about the finer product by using the roller mills that is 99 percent of the product you can expect to have a kind of a size smaller than the 200 mesh screen that is they can pass through the 200 mesh screen. So, then you can have a kind of guarantee of such a finer product if you are looking for very fine product so it is better to go for a kind of a roller mills with classifier.

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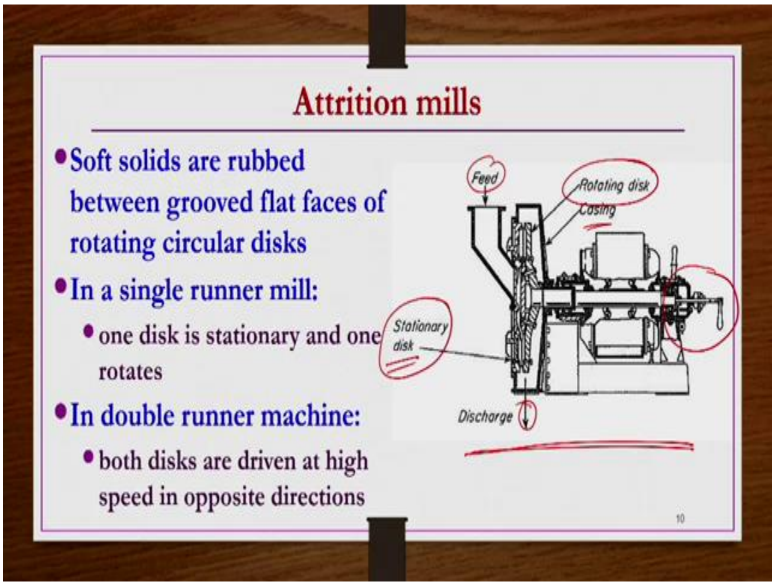

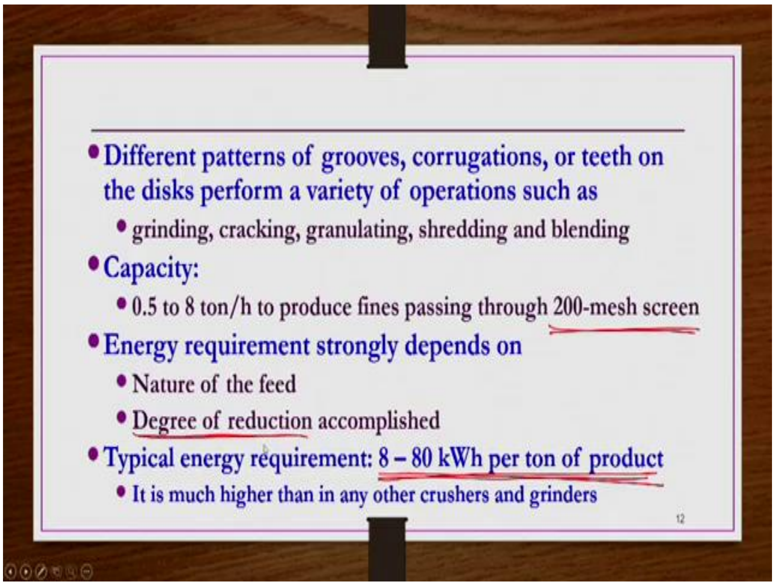

Attrition mills, attrition mills as the name indicate what are they a kind of attrition is taking place in order to get the size reduction. So there may be two surfaces between these two surfaces material may be trapped and then when the one of these surface out both the surfaces are rotating in a different direction whatever the material trapped between them that will be undergoing some kind of size reduction. So usually these attrition mills we use for the kind of fine material production. So the feed size cannot be very large feed size for this attrition mill should be less than that equals to 6 mm as already mentioned in one of the lectures.

So we see one of the attrition mill here, so as shown here there are a there two disk. One of them is rotating another one is a kind of a stationary disk and these disks are inside a casing. The feed is coming over the top from here. So whatever the material that is trapped between these disk. So because of the rotation of the one of the disk that that required size reduction is taking place and then whatever the product is there that is collected from the bottom through a discharge. The rotation is provided by these kind of you know shaft motor connection etcetera are given here. Rotor is there and then that is connected to the shaft. So, when it is moving that one of the disc is rotating.

So this is the basic principle about the attrition mill. So, what happens in attrition mills in general, soft solids are rubbed between grooved flat faces of rotating circular disk. So, they are circular in shape usually disk they are rotating in in different directions with different speeds. So whatever the softer material that is trapped between these two these that will be undergoing some kind of rubbing action and then because of the rubbing action size reduction is taking place. There maybe two types of attrition mills, one is a single runner mill another one is the double runner mill.

In the single runner mill one disk is stationary and one rotates as shown here. So, this is a kind of for the single runner mill because one of the disc is stationary whereas the other one is rotating. In the case of a double runner machine both disks are driven at high speed in opposite direction. In double runner machines both of them may be going through a kind of very high speed rotation and then they will be rotating in opposite direction so that the reduction degree would be high so the rotation speed also very much higher in the case of a double runner machine compared to the single runner machine.

The feed enters through an opening in hub of one of the disc as I mentioned. Further it passes outward through narrow gap between the disc and discharge it from periphery into a stationary casing. Width of the gap is adjustable depending on the feed size if your feed size is a kind of having 5 to 6 or 4 to 5 mm so accordingly the gap between these two disk can be adjusted if you are having let us say feed in a 1mm or 2mm size then the gap may be reduced so that you know the feed may be trapped comfortably between the disc and then size reduction taking place so the gap is very much adjustable.

And then having at least one grinding plate spring mounted is beneficial because what happens if at all there is unbreakable material is trapped between these the these two disks so this can separate them if unbreakable material gets into the mill by having a kind of a at least one grinding blade is spring mounted is a spring mounted. Otherwise what happens if some kind of unbreakable material is trapped between disks? The disk maybe damage in general so if you have a kind of spring mounted disk you know even if some kind of unbreakable material is coming and then being trapped in between.

So because of the spring action that disk may be moving away and then protecting itself from being damaged because of the unbreakable material because these this kind of attrition mills in general used to for used for kind of a soft materials which can be size reduced comfortably without much difficulty. If the material is very hard so such kind of materials are very difficult to be handled by the these attrition mills. However, it is not possible to avoid such kind of circumstances in real life conditions. So, whenever we have such kind of unbreakable material and being trapped between disk so having a spring mounted disc would be very much helpful.

So that it can protect itself, this spring mounted plate can be moving away and then letting the material to pass out and break unbreakable material to pass out. From the gap between these two disks. So, in general different patterns of grooves, corrugations, or teeth on the disk perform a variety of operations so it is not necessary that you should always have a kind of flat surface disk only you can also have a kind of disk with different kind of patterns like you know grooves, corrugations, or teeth that is also possible. So if you have a different types of patterns on these disks so then you can expect different kind of operations such as grinding, cracking, granulating, shredding and blending.

Capacity of these attrition mills in general small 0.5 to 8 tons per hour to produce fines passing through 200 mesh screens. The attrition mills are in general kind of a fine reducing material there may be some kind of intermediate material as well but primarily purpose of this attrition mills is to produce the fine material by the attrition out rubbing kind of action. So it is expected that the product that is coming out from the attrition mills they should be able to pass through large mesh number screens something like 200 mesh screen something like that so that you know one can get the finer material.

Here also the energy requirements strongly depends on the nature of the feed and the degree of reduction accomplished. It is not necessary that whatever the material is coming in that entirely is being crushed. That is not possible in all kinds of machines. Only in hammer mills it is possible that whatever the material the a solid material that is entering that is definitely being hammered by the swinging hammers but that kind of action is not possible always. So the degree of reduction is also kind of a important factor in these attrition mills in order to decide the energy requirement in addition to the feed the degree of reduction is also a kind of a important factor to decide the energy requirement for attrition mills.

Typical energy requirement for these attrition kills is in general 8 to 80 kilowatt hour per ton of the product. Though it looks like a good number like in 8 to 80 kilowatt hour per ton of product. It is very much higher than any other crushers or grinders that we have discussed so far. So for whatever the crushing equipment that we have studied like jaw crusher, gyratory crushers and then roll crushers then we have seen the, we have also seen the hammer mills. We have also seen roller mills. So, compared to all of them whatever the energy requirement that is shown here that is very much higher. That is in any other kind of crushers and grinders. The energy requirement is not such high as for these attrition mills. That is because it also depends the energy requirements in the attrition mills it also depends on the degree of reduction that has been accomplished in general.

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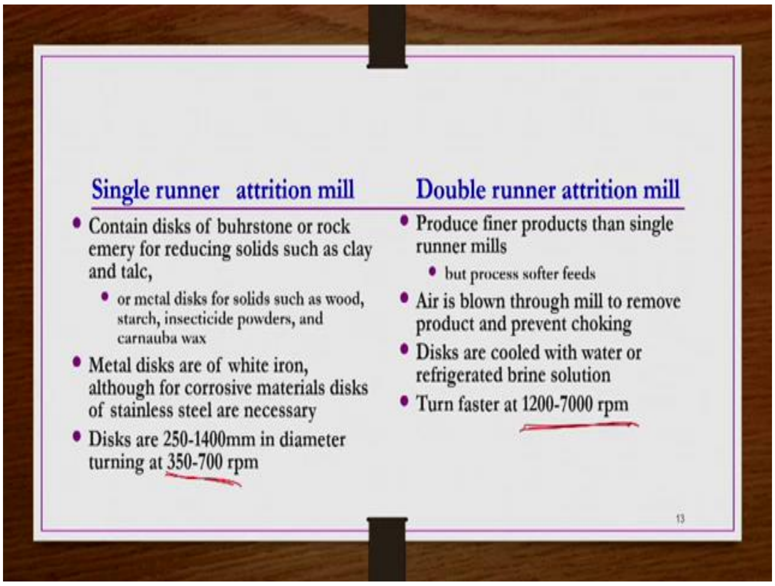

Now we see difference between the single runner attrition mill and double runner attrition mill. What happens, what type of materials in general they handle and those details we compare. In single runner attrition mill, it contain disk of buhrstone or rock emery for reducing solids such as clay and talc. In general disk can also be of metal disk which are more suitable for solids such as wood, starch, insecticide powders etcetera.

Metal disc in general are of white iron although for corrosive materials disc of stainless steel are also be used in general. If you have a kind of corrosive materials to be undergo for size reduction using this attrition mills. And disc in general how about 250 to 1400 mm in diameter in the case of single runner attrition mill and they run at moderate speed 350 to 700 rpm whereas in the double runner attrition mill they produce finer products than single runner mills in general. Because of you know both the disk are rotating and they are rotating in the opposite direction and they rotate at much higher speed compared to the single runner attrition mills.

So that is the reason double runner attrition mills produce finer products than single runner mills. However, they can process softer feeds in general and then in this double runner attrition mills, air is blown through a mill to remove product and then prevent choking otherwise choking may take place. Disks are cooled with water or refrigerated brine solution. And then it run very faster up to you know 7000 rpm from 1200 to 7000 rpm such high speed disk in double runner attrition mill rotates. Both of them are rotating in opposite direction and they rotate at very high speeds as high as 7000 rpm.

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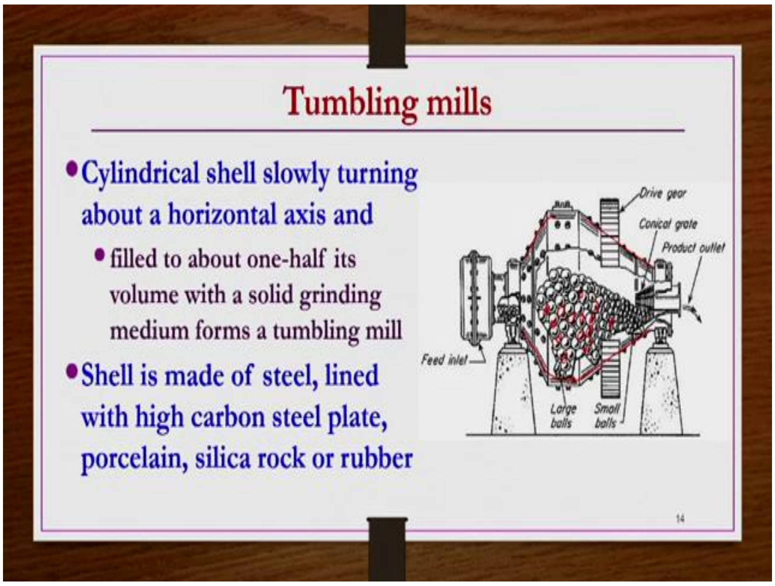

- Grinding medium is
  - metal rods → rod mill
  - lengths of chain or balls of metal, rubber, or wood → ball mill
  - flint pebbles or porcelain or zirconia spheres → pebble mill
- For intermediate and fine reduction of abrasive materials
  - tumbling mills are best option
- Tumbling mills can be continuous or batch

- In a batch machine
  - Known quantity of solid to be ground is loaded through an opening
  - Opening is then closed and
  - Then mill turned on for several hours
  - It is then stopped and the product is discharged
- In a continuous mill
  - Solids flows steadily through the revolving shell

- Grinding elements are carried up side of the shell nearly to the top,
  - from where they fall on particles underneath
- Energy expended in lifting grinding units is utilized in reducing size of the solid particles

Now we see tumbling mills. In tumbling mills, we have a kind of casing. Usually cylindrical casing and then in that casing we take the grinding medium, grinding medium different types of grinding medium are there. Here we have shown for a convenience you know, balls we have shown they can be rods, they can be chains, they can be pebbles also depending on the applications. So then you take up to one up to half of the size of the disk casing filled with this grinding medium.

And then whatever the solids that you want to crush that you can take in this material and then you rotate the is cylindrical casing in in a particular direction for some time and then you take the product out. So what happens in while they are rotating, these balls, let us say balls are there. They will be lifted up and then they almost go to the top of the top surface of the cylindrical shell and then they fall down because of the gravity. When they fall down they will be showing impact on a kind of solid particles underneath and those particles will be broken down into the smaller size.

That is the principle in general any of tumbling mills. Within the tumbling mills we have the rod mills, we have the ball mills, we have the pebble pebble mills etcetera. Those names are different but the process is same only that the grinding medium are different from one tumbling mill to the other tumbling mill but otherwise principle, working principle is kind of the same. So, that is about the tumbling mills in tumbling mills we have a cylindrical shell slowly turning about a horizontal axis and filled to about one half its volume with a solid grinding medium that forms a tumbling mill.

So, the solid grinding medium are in general as I mentioned they can be rods, they can be balls, they can be pebbles and they can be chains also sometime. This shell is made up of steel lined with high carbon steel plate, porcelain, silica rock or rubber any type of shell we can have in general we can have shells of different types of material like steel or steel lined with the high carbon steel plate, porcelain, silica, rock or rubber kind of things. Grinding medium is in general metal rods in kind of rod mill.

If you use the metal rods as a kind of grinding medium, then those tumbling mills are the can be referred as rod mill. If you use a lengths of chains or balls of metals, rubbers or wood, wood balls, rubber balls, metal balls or metal chains etcetera, then you can say such kind of tumbling mills as kind of a ball mill. Then you can also use flint pebbles or porcelain or zirconia spheres in general. So such kind of tumbling mill we can say pebble mill. So, all these different types of mills are same similar same like under comes under the tumbling mill category.

Only by the change of the grinding medium different names are given. For intermediate and fine reduction of abrasive materials, it has been found that these tumbling mills are the best option. Tumbling mills can be continuous or batch one can operate them in continuous mode. One can operate in a kind of batch mode. In a batch mode what do you take the feed and then you insert the shell you take the solid feed which you wanted to break and then close the feed opening entrance and then you rotate the shell for some time two to three hours at a specified speed and then stop it then you collect the product. So that is happens in general and a kind of a batch tumbling mill in a kind of continuous tumbling mill what happens.

We can have a kind of a continuous feed as well as the product collections both ways it is possible. So, in a batch machine known quantity of solid to be ground is loaded through an opening. Opening is then closed and then mill turned on for several hours, it is then stopped and then the product is discharged In a continuous mill, solids flows steadily through the revolving shell and then collected continuously from the discharge opening.

Grinding elements are in general carried up side of the shell nearly to the top like let us say cross section of shells if you see let us say in two dimensional way this is the shell. And then let us say we have several type of balls like this. We have already filled, now and then we have also taken the solid material that is need to be crushed here. So, when this shell rotates it is in this direction whatever the balls are there they will also move up like this.

They will also move up in general, almost they go up to the top of the shell and then they will fall down. Sometimes they may fall down after the reaching to a certain height, not cannot not almost up to the top of the shell. So those also may fall down when they fall down. They show a kind of impact on the particles underneath them and then those particles will go size reduction. So, from that top wherever up to whatever the height they reach from there, they fall on the particles underneath so that to have a kind of required size reduction operation. Energy expended in lifting grain grinding units is utilized in reducing the size of the solid particles.

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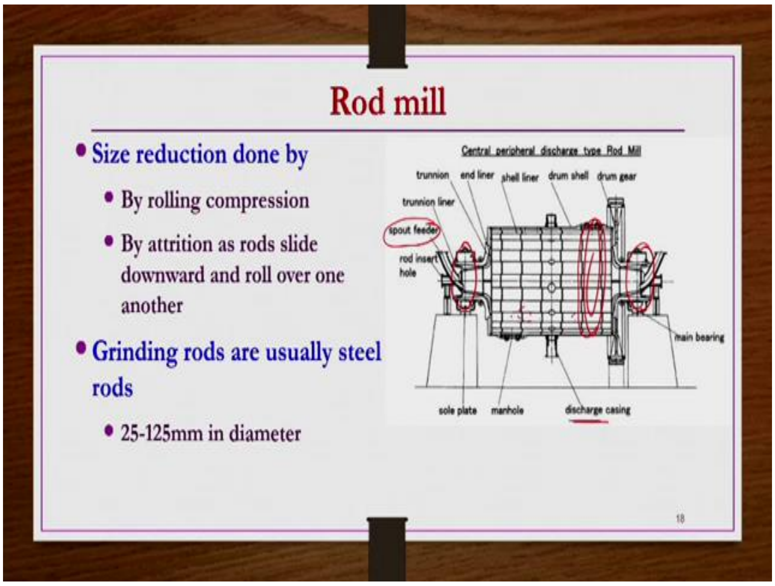

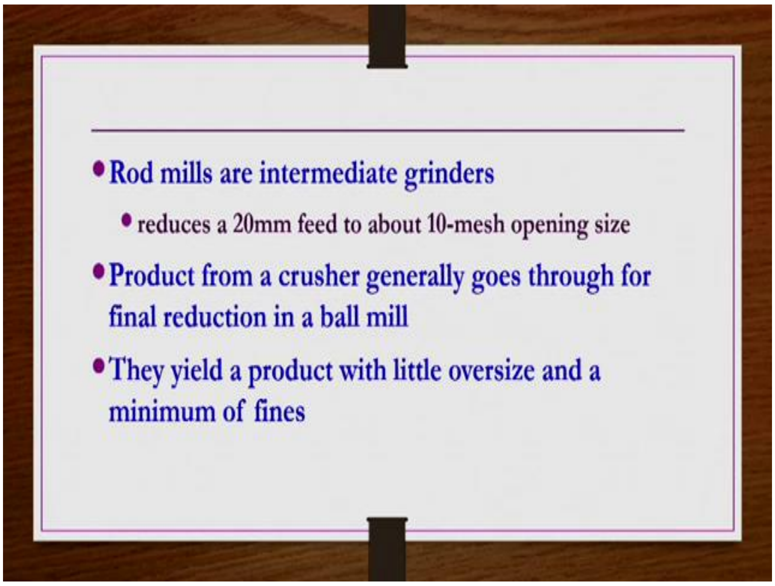

Now we see individual details of this tumbling mills. We start with the rod mills then we will see the ball mill and pebble mills etcetera. In the rod mills, we have a casing like this. Within this casing, we have several kind several number of rods are there inside this particular container that has been shown here. So, the feed material is coming from here. This one this shell is rotating in such a direction. in one particular direction. So the rods will also the rods will also kind of you know moving in that particular direction of the rotation.

So, once they reach the top of the almost top of the shell they will fell down and then they will have a kind of impact underneath the particles whatever are there and then size reduction takes place. Whatever the size reduced material are there, they will be collected from the discharge casing from here. So remaining these details shown here in the picture there are kind of design purpose how they are running kind of thing but basically physics is this.

Here side reduction done by rolling compression as velocity attrition also because when the shell is rotating the rods are sliding downward and rolls over one another. So, because of that one when the rods are roll rolling one on another what happens are kind of attrition takes place and then whatever the material trapped between these rods they will be undergoing a kind of attrition action and then size reduction takes place.

Grinding rods are usually steel rods, in general then they are having a diameter 25 to 125 mm in general and then it is not necessary that we will take only one particular size rods as a kind of grinding medium. We in general have a range of you know rods of different diameters can be taken as a kind of a grinding medium. Rod mills are intermediate grinders which in general reduces 20mm feed to about 10 mesh opening size. Product from a crusher generally goes through such kind of tumbling mills for a final reduction. And they yield a product with little over size and a minimum of fines.

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Next one is the ball mill are pebble mill. Here as I shown schematically we have these balls shown as a kind of you know same size but you can have a different size balls also. You can have different size balls also and these are the solid material that that needs to be crushed out. So, when it rotates let us say in this direction so balls what happens, they will be lifted along the rotational direction like this and then sometimes they may reach to the top all almost to the top of the shell.

Sometimes they may not reach up to the top of the shell and then they fall down. and when they fall down they have a kind of impact on these particles that solid particles which are to be reduced and then by that impact you know size reduction takes place. Here reduction is done by impact as the balls or pebbles drop from the top of the shell. In a large ball mill shell can be as bigger as 3 metres in diameter and 4.25 metres long. Such large ball mills are also possible and then balls can be 25 to 125mm diameter in size. Pebbles can be 50 to 175 mm diameter as well.

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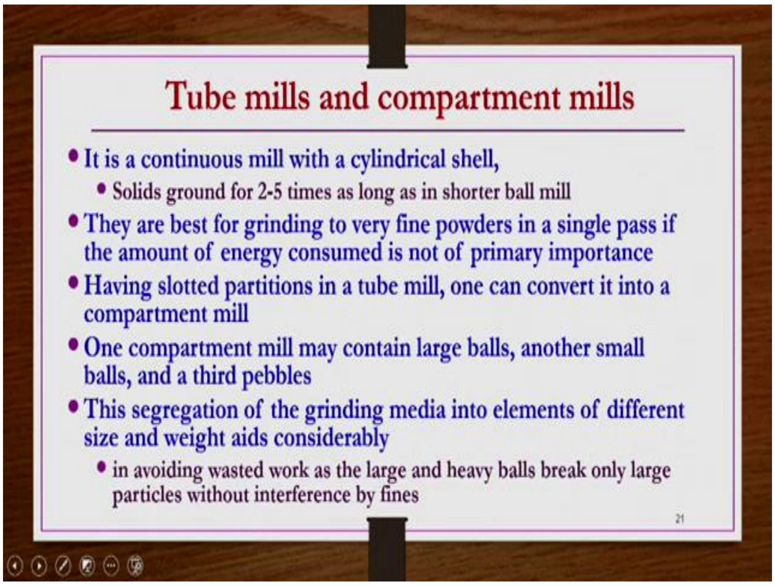

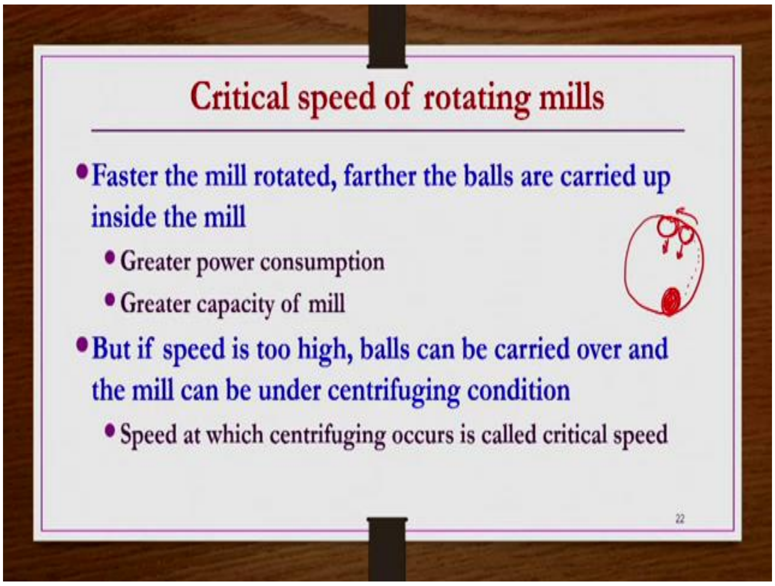

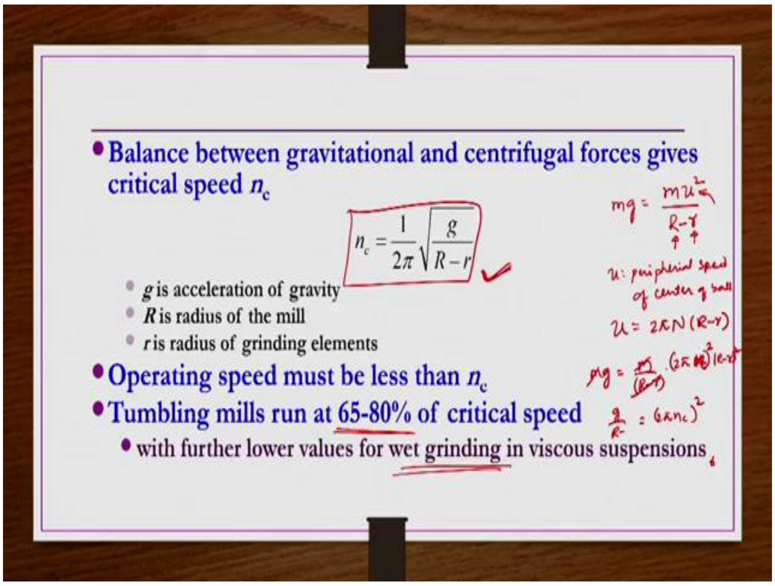

Next one is the tube mills and then compartment mills. Tube mills and compartment mills like you know in these ball mills or rods mills what we are doing we are taking all type of or all sizes of the balls or the rods in one particular casing and then rotating. to have a kind of size reduction. Let us say we have a ball mill. If you take a kind of a 25 mm ball, if you have a 50 mm ball and then you have a kind of you know 100mm ball. Let us say or 75 mm ball when they are rotating when the shell is rotating the ball these balls will also rotate and reach to almost to the top of the shell and then they fall down.

When they fall down they are going to crush only the bigger particles as bigger as this you know balls are slightly smaller than them but they are not going to have a kind of a impact on smaller particles. Some particles later say to them and particles let us say 2mm particle they are not being affected by the such bigger particles because these that feed is coming that feed may be having all sizes of the particles so only bigger size particles may be broken by these bigger sized balls. Whereas the smaller sized materials small feed material may not be having a much effect of these falling balls. So the reduction of such kind of fine smaller particles is further not possible.

That is the reason what we have we can have a kind of compartments so that in one particular compartment you can have a kind of a larger sized ball in another compartment you can have a kind of smaller size balls and then in other compartment you can have a kind of medium sized balls and then do the size reduction. That is the purpose of this tube mills and compartment. So that you know you have a kind of efficiently using the energy that is provided for the rotation of these shells. Tube mills and compartment mills, it is a continuous meal with a cylindrical shell. Solids ground for two to five times as long as in a shorter ball mill in general.

They are best for grinding to very fine powders in single pass if the amount of energy consumed is not of primary importance. Having slotted partitions in a tube mill, one can convert it into a compartment mill. One compartment mill may contain large balls, another may containing the small balls and the third one may be containing pebbles. So this segregation of the grinding media actually in compartment mills, what we are doing, we are segregating the grinding media because you know to avoid wastage of work as the large and heavy balls break only large particles without interference by fines.

So, that is the reason we are segregating this grinding media in compartment mills. So by doing this compartment energy wastage would be reduced. So in these tumbling mills, you know we have seen kind of the outer shell the shell containing the grinding media and in solid particles which are to be undergoing a size reduction are taken inside a shell and then that shell is rotating. So, what should be the speed of shell rotation, etcetera. that should be kind of very much important. So if you have a lower speed then the efficiency may not be good.

It may not have a kind of a produce the product of required size. If you are rotating at very large speed what happens these balls and particles all of them may be undergoing a kind of centrifugation without having kind of any kind of interaction amongst them. So, there will not be any reduction anyway so there is a kind of optimum rotational speed is required for these rotating mills or tumbling mills which which are whichever of them are rotating in a kind of direction. So those critical speed details we see now. So what we can understand in general faster the mill rotated, farther the balls had carried up inside the mill almost to the top of the shell of the mill.

Then in under such conditions if you are rotating faster. Obviously the power consumption would be more and then greater capacity of the mill will anyway be existing. But if speed is too high, balls can be carried over and then mill can be under us in the centrifuging conditions so under centrifuging condition there will not be any kind of considerable interaction between balls and in solid particles that are to be crushed. So there should be a kind of optimum speed are the critical speed beyond which one cannot operate these rotating mills.

So that speed is known as the speed at which centrifugation occurs. Speed at which centrifugation occurs is called the critical speed that we can find out. How we can found out that one? We can do a kind of a forced balance in order to get this critical speed so the forced balance like you know when these balls are moving up. So, when it is rotating like this the balls let us say take single ball that is moving up like this along the surface. It may reach up to this point. It may also reach up to this point and then fall down.

So, this is, the rotation is because of the centrifugation or rotational forces and then centrifuging forces and then the settling the falling of this ball after reaching certain height is because of the gravity force. So if you make a balance between the gravity force and then force due to the rotation that is centrifuging force then we can get a kind of some number some expression for this critical speed. That is what we are going to see now.

So balance between gravitational and centrifugal forces give critical speed let us say gravitational force we have "mg" and centrifugation force $mu^2/_{R-r}$, they should be R effective. This R is the radius of the shell and then the r is the radius of the ball that is being lifted. So, this u is a kind of a peripheral speed of centre of ball. This u is peripheral speed of centre of ball. Now using this equation, you can get a kind of a expression for the critical speed. So this u can be related to rotational speed N, rotational speed N. So in that way if you see this

$u = 2N\pi(R - r)$.

So now this u you can substitute there and then do the simplification to get the critical speed. Let us say that the $mg = \frac{m}{R-r}(2\pi N)^2(R-r)^2$. If you take the speed at a critical condition are n_c small n_c. Let us say n_c I am taking because I have written in n_c. So, then what we have this R minus r and then this square is gone m and m is gone so what we have $\frac{g}{R-r} = (2n_c\pi)$ or $n_c = \frac{1}{2\pi}\sqrt{g}$.

So this gives us the critical speed beyond which one should not rotate the shells, one should not the rotating mills. Otherwise there will kind of a centrifuging will dominate and then the particles will be carried over in a including ball would be carried over because centrifusion. So, that expression we have written here $n_c = \frac{1}{2\pi}\sqrt{\frac{g}{R-r}}$, where g is the acceleration of the gravity. R is the radius of the mill. Small r is the radius of the grinding element or grinding medium that is ball or bubbles etcetera.

And then operating speed must be less than n_c that is the critical speed then only there will be kind of proper interaction between the grinding medium and then solids and the solid material it is to be crushed. In general tumbling mills run at 65 to 80% of the critical speed. You cannot even go close to the n_c critical speed value. In general tumbling mills, industrial tumbling mills rotate at 65 to 80% of the critical speed. With further lower values for wet grinding in viscous suspensions.

Let us say if you have a kind of a wet grinding rather than the dry grinding having viscous suspensions in the shell, then you need to have a critical speed much smaller than the 65 to 80% of the n_c critical value. So, this whatever the nc value is given that is for the dry grinding only and then in in reality tumbling mill tumbling mills operated up to 65 to 80 percent of this n_c only 65 to 80% of n_c in general but if you have a wet grinding conditions this operating speed of the tumbling mills must be much smaller than the 65 to 80% of n_c.

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This is about the grinders the texts, the figures that have been presented in this lecture are taken from this reference books. So, majority of details you can find in this McCabe and Smith book from where I have taken the texts and pictures. There are some details in this book also but however this book Richardson and Harker is very good especially if you wanted to have a more details of several different types of industrial mills, industrial grinders etcetera then you can refer this third reference book Richardson, Harker- Coulson and Richardson's Chemical Engineering Series Second Volume. Thank you