Fundamentals of Food Process Engineering
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Lecture - 39
Size Reduction (Contd.)

Hello everyone. Welcome to the NPTEL online certification course on Fundamentals of Food Process Engineering. Today will continue with the topic of size reduction.

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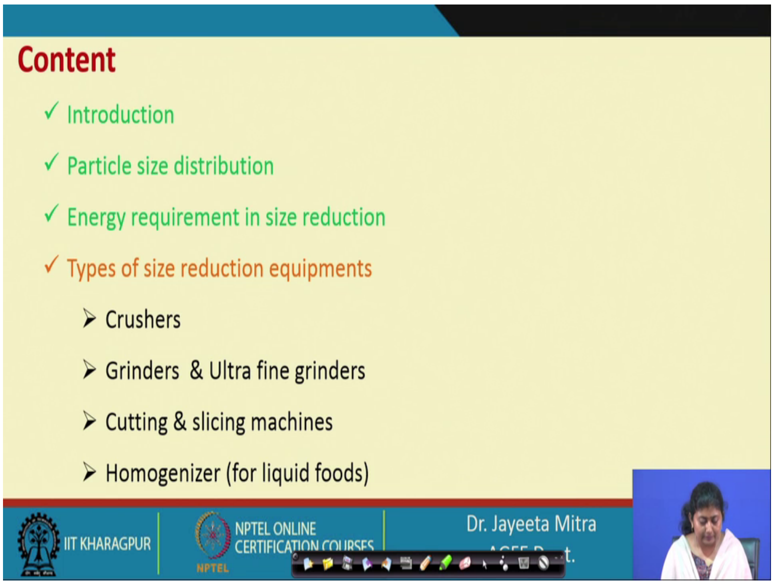

In our previous classes we have discussed about the introduction and particle size distribution then energy requirement in size reduction, ok. And then we have move on to the different types of size reduction equipments. That we will discuss today. So, in that we have crushers, grinders and ultra-fine grinders, cutting and slicing machines, and homogenizers which is for liquid foods. So, first we will see one by one that what are the different category in which we can classify the various size reduction equipments, and what are the functions, and what are the speciality or characteristics of all those equipment.

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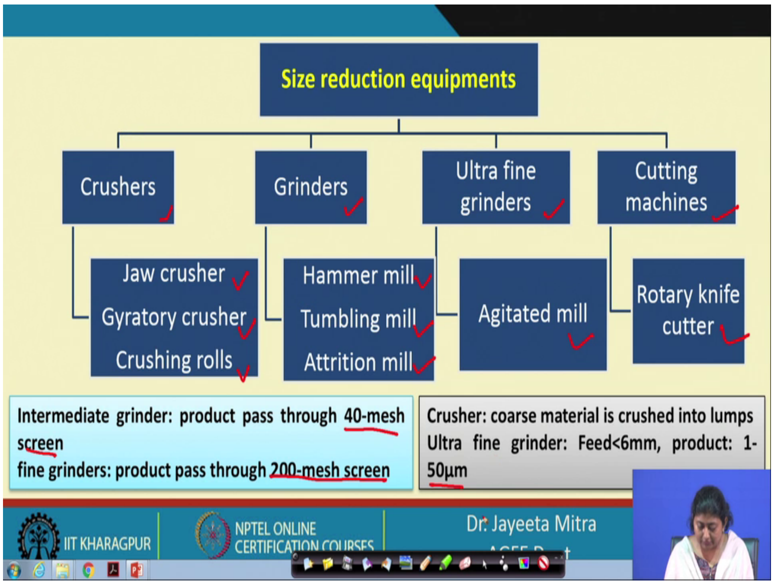

So, here is the flow chart; which shows different kind of size reduction equipments. Starting from the left here is a crusher ok, then grinders, then ultrafine grinder, cutting machines. In the crushers we can get again different kind of crushers, which is jaw crusher then gyratory crusher crushing rolls, then we have different grinders such as hammer mill, then tumbling mill attrition mill, ok. In the ultra-fine grinders, we are getting agitated mills.

And in the cutting machines we have rotary nice cutter. So, all this work on certain principle of impact, compression, shear or cutting mechanism and most of the cases not only one single method, but maybe more than 2 in combination 2 or more than 2 forces are applying in different size reducing equipments.

So, if we considered the grinder we can we can again classify them into intermediate grinder and fine grinders. Intermediate grinder they produce the product which can pass through 4ty mesh screen, ok. We will discuss in detail today what is the 40 mesh screen how this specification of mesh size has been done, and fine grinders which can pass through the product 200 mesh screen, ok.

And crushers are generally used for the coarse material ok, and they crushed into lumps. Ultrafine grinder such as agitated mill so, the feed is generally less than 6 mm and product is varied from 1 to 50 micrometre. So, we can see that there are various range of product as well as feed also in some cases we cannot give higher size feed into that particular mill. So, now, we will see in a bit detail about all such equipment.

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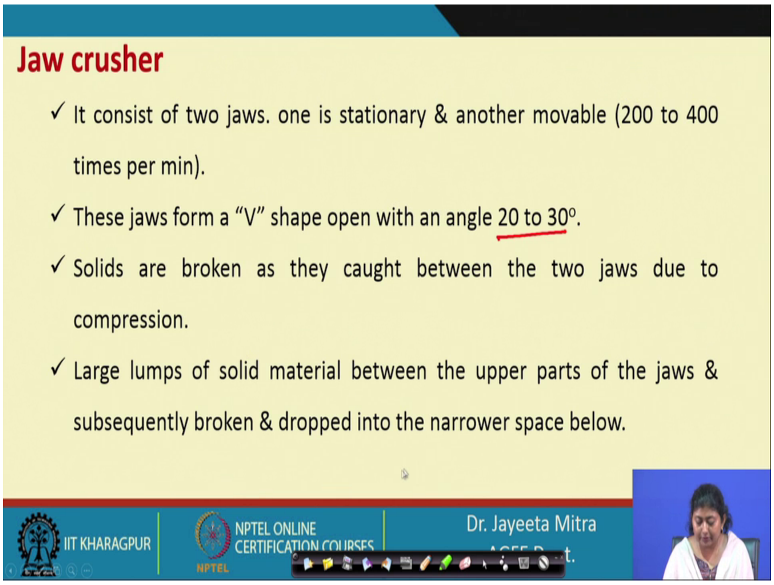

First is jaw crusher ok; jaw crusher, it is a particular crusher consists of 2 jaws. One is stationary and another is movable ok.

So, it moves at about 200 to 400 times per minute. And these jaws form a V shape opening with an angle which may vary from 20 to 30 degree. And solids are broken as they caught between the jaws due to compression. So, when we feed the product, we can feed by direct feeding or by hopper or the maybe some you know feed roll, which is controlling the rate of feed. And when they come into this V shaped grove, which is having an angle between these 20 to 30, 20 to 30 degree. So, then the solids are broken, between the 2 jaws because of the compression force.

Large lumps of solid material, between the upper part of the jaw, ok. They will come and subsequently broken and dropped into the narrower space below. Because since is a V shaped grove. So, the upper part which is having a broader part therefore, the lumps are coming and in the bottom section where the space is narrowed down there the broken particle will dropped into.

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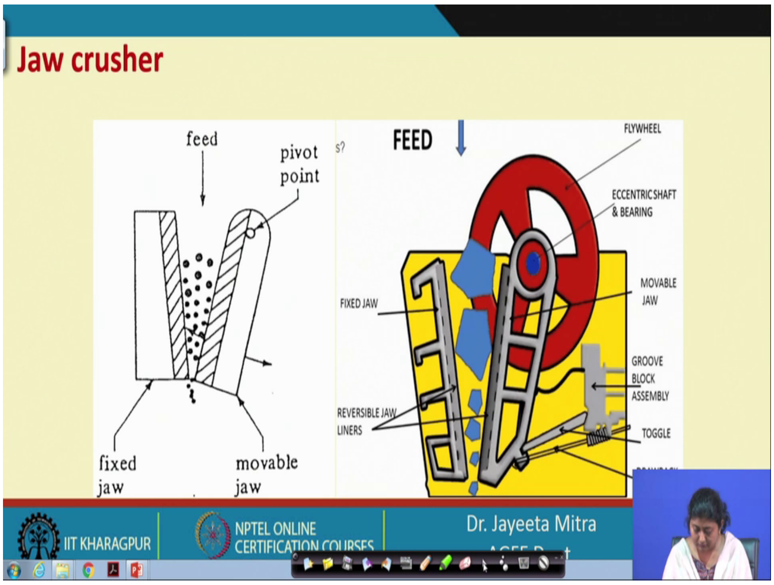

Here is the diagram of jaw crusher, ok. And here the feed is coming into the broader section, then because of compression, it gets into smaller particle and from the narrow space at the bottom it is coming the this jaw is left one is fixed one, and this right one is movable based on that pivot joint and the angle is maintained as 20 to 30 degree as mentioned.

There are sometime feed roll flywheel is provided to pass this material to the grove, ok. So, there are may be a different kind of arrangements, but mostly the principle will be based on compression force the particle the larger size particle will be will be you know reduced to a smaller size even though this size is higher than the grinders, ok.

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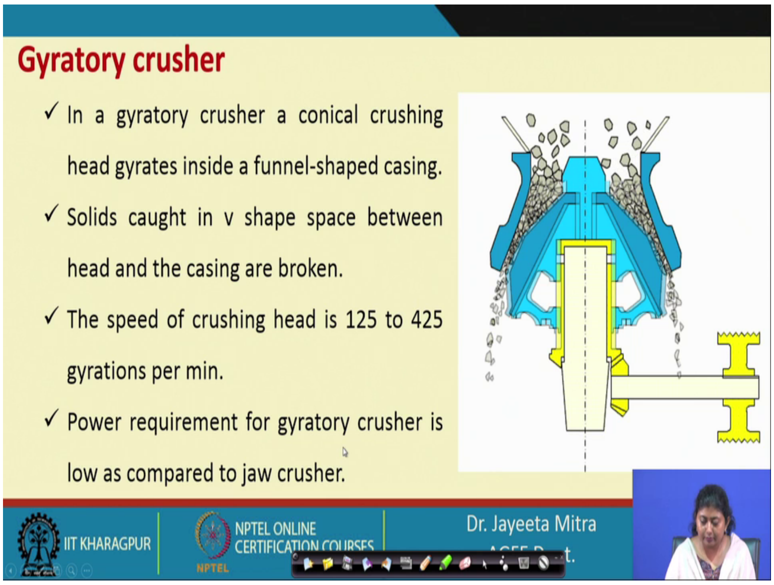

Then gyratory crusher ok. So, we can see that there is a gyratory movement that can takes place in the inner cylindrical or the conical shaped portion. And from all the side; that means, from the inner core and the periphery or the or the casing in between these 2 the product is coming. And then the product is crushed and produced in the shape. So, in the gyratory crusher a conical crushing head gyrates inside a funnel shaped casing.

So, this is our conical crushing head. So, solid caughts into the V shaped space between head and the casing. So, in the in between these section, and in between these section in the in the annular space basically so, that will caught and then they we will break. The speed of crushing head is 125 to 425 gyration per minute. And power requirement for gyratory crusher is low as compared to the jaw crusher, ok. So, because of this gyratory movement, the less force is required to break this and power requirement is also less, which is high in case of the jaw crusher.

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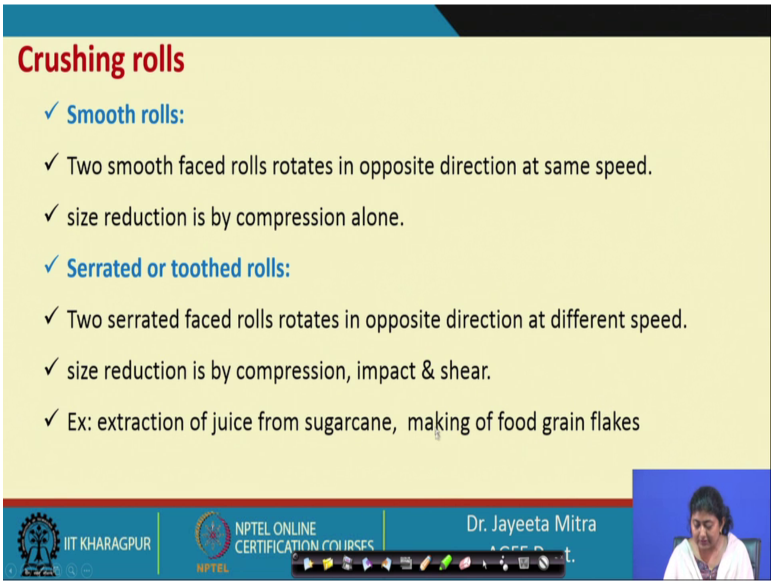

Now, moving on to the next equipment that is crushing roll.

So, in crushing roll we can use the smooth rolls to smooth faced roll, rotates in opposite direction at same speed. And size reduced by compression alone. There also can be serrated or toothed rolls. So, 2 serrated faced rolls rotates in opposite direction at different speed. So, we can see carefully that when we use the smooth faced rollers, ok.

So, they rotate in opposite direction at the same speed but when we use serrated roll, ok. So, they rotates in opposite direction at differential speed. So, that means, all this different kind of arrangements needed for different kind of requirement. Different grain size and different kind of particle size reduction. So, when we want a shear kind of effect, we apply certain differential speed. So, that you know it will break, and then the upper surface and the lower surface will be getting differentiated, ok. So, these are the mechanism.

So, here in the second case as I mentioned that along with the compression which was there in the first case. Shear and impact will also be there. So, for the smooth roll size reduction is because of compression alone for the serrated or toothed rolls size reduction is by compression impact, and that is sudden blow; sudden high blow of force and also because of the shear. For example, extraction of juice from sugarcane making of food grain flakes. So, all this for food grain flakes we use the serrated kind of toothed rolls.

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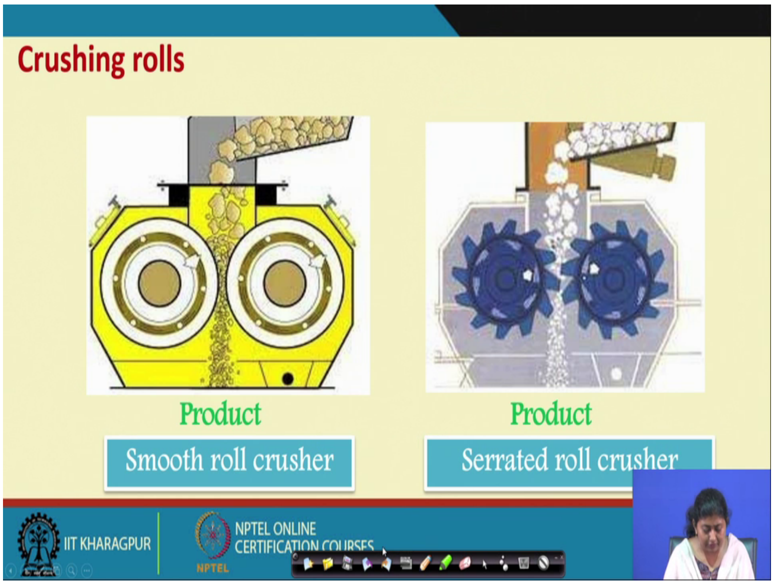

So, these are the crushing roll, we can see here 2 smooth rolls are there moving at a same speed and here we can see that there is a serrated rolls are there, which is moving at a differential speed and product coming out of that and the grinding I mean crushing will takes place.

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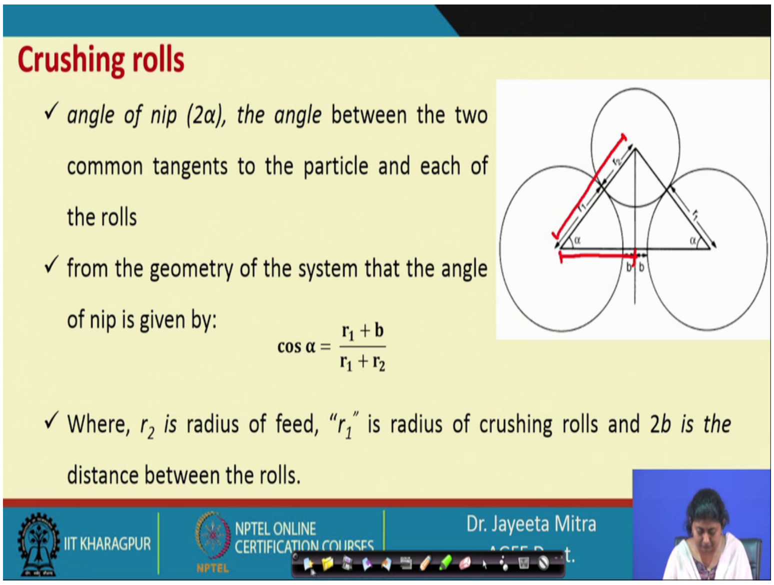

So, in this particular case when we want to analyze further that what will be the angle when the when the product is coming in between these 2 rolls, we can analyse angle of nip, ok. Angle of nip 2 alpha, which is actually angle between the 2 common tangent to the particle common tangent to the particle and each of the roll, ok.

So, actually if we take certain you know product in between 2 rolls; let us say this is one roll and there is a little gap when the product will be there. And there will be another roll. So, that that 2 common tangent to the particle and each of the role. So, if we make that common tangent here ok. So, we can get the angle of nip that is coming 2 alpha ok. So, here instead of that particle we have taken a roll which is representing the product, and here the roll of the crusher having the radius of r 1 this one also r 1 the second one also r 1 because the dimension should be similar, ok. And here this one is the product that that is having radius of r 2, and the gap between this vertical line from the centre of that product to the peripheral distance of the roll that is b.

And the angle it has made at the centre did the centre line of this product and the rate and the centre line of the roll in both the cases. So, they are making an angle alpha. Now, from the geometry of the system that the angle of nip we want to calculate so, the value of alpha if you want to calculate. So, from this if we take cos alpha so, cos alpha will be cos alpha will be r 1 plus b divided by r 1 plus r 2.

So, for this one if we consider this distance and this distance. So, based on that we are making the calculation, cos alpha equal to r 1 that is the radial distance plus b the gap and here it is r 1 plus r 2 ok. So, this we have already mentioned that r 2 is the radius of feed that any feed that we are giving in the crushing roll. And then finally, the product will come out of that. So, r 2 is the radius of feed r 1 is the radius of crushing roll, 2 b is the distance between these 2 rolls.

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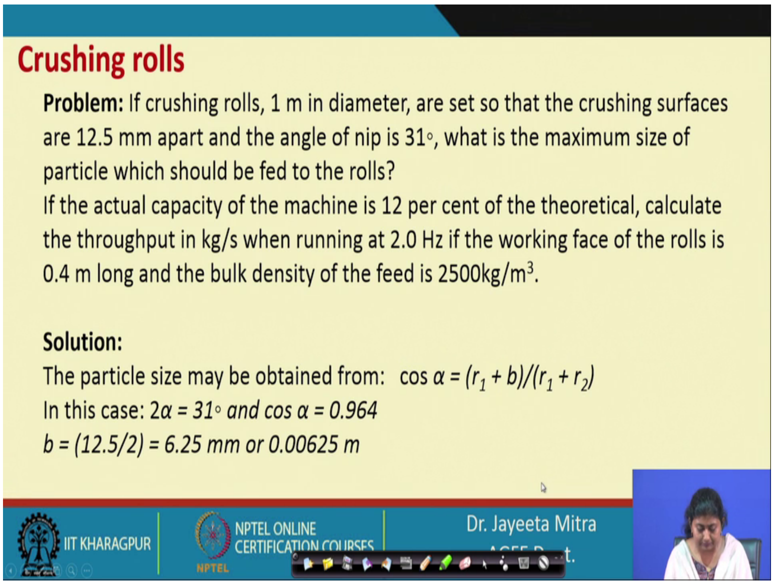

Now, if we take a problem that if crushing roll one metre in diameter are set. So, that the crushing surface are 12.5 mm apart, and the angle of nip is 31 degree, what is the maximum size of the particle which should be fed to the rolls? And if the actual capacity of the machine is 12 percent of the theoretical capacity; calculate the throughput in kg per second; when running at 2 hertz if the working face of the roll is 0.4 metre long. And the bulk density of the feed is 2500 kg per metre cube. Now, will see how we can solve this. First we need to calculate the value of the angle alpha. So, from here the particle size may be obtained.

Because nip angle 31 is given now, we need to we need to calculate the particle size that that can be calculated from this data. So, nip angle that is to alpha is 31 degree. So, cos alpha 0.964 and from here we can calculate the value of b. So, b will be 12.5 divided by 2, because this was the gap given 12.5 mm apart. So, we are getting 6.25 mm or 0.00625 meter.

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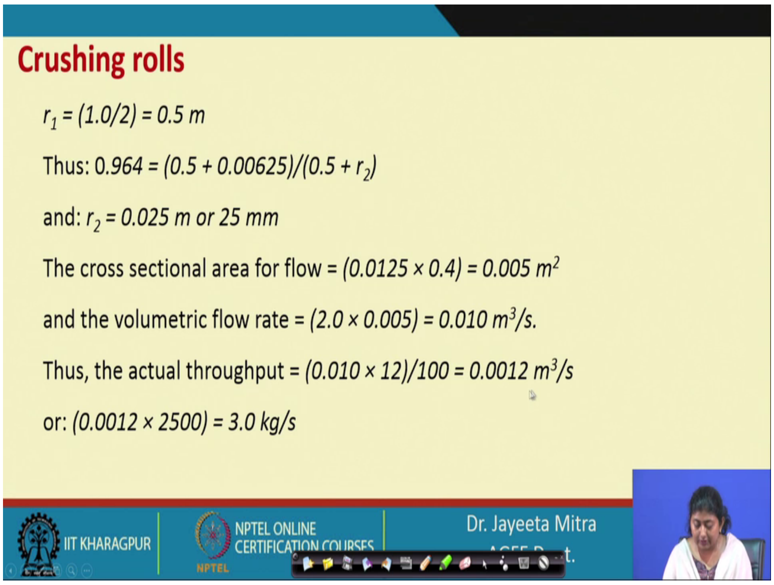

Now, r 1 is equal to 1 by 2 that is 0.5 mitre, supporting the value of this cos alpha this is equal to r 1 plus b divided by r 1 plus r 2. So, we are getting r 2 has 25 mm. So, r 2 was the radius of the feed. So, the feed size is 25 mm. Now, the cross sectional area for flow is 0.02 0.0125 that is the gap between these 2, and the length was 0.4. So, 0.005 metre square is the cross sectional area or flow. And the volumetric flow rate will be 2 into 0.002, 0.005. So, this much metre cube per second.

So, cross and cross sectional area is given multiply with the velocity we are getting the volumetric flow rate. Now, the actual throughput will be 0.010 into 12 divided by 100. So, here we are getting 0.012 metre cube per second. And if it convert this to kg per second we will multiply this with the density of this material. So, it is 3 kg per second. So, we will see if all the query has been answered.

Yes, actual capacity of the machine is 12 percent that we have taken. Calculate the throughput in kg per second when running at 2 hertz actual frequency. And 0.4 mitre bulk density this one fine. So, we have calculated all the parameter that has been asked here, ok. So, this is the frequency that has been given, this is the area. Now, from that the actual throughput will be the percentage we have to take 12 percent of that. So, that is why we are getting this one, and with that multiplication of the bulk density we are getting capacity in the actual throughput in kg per second.

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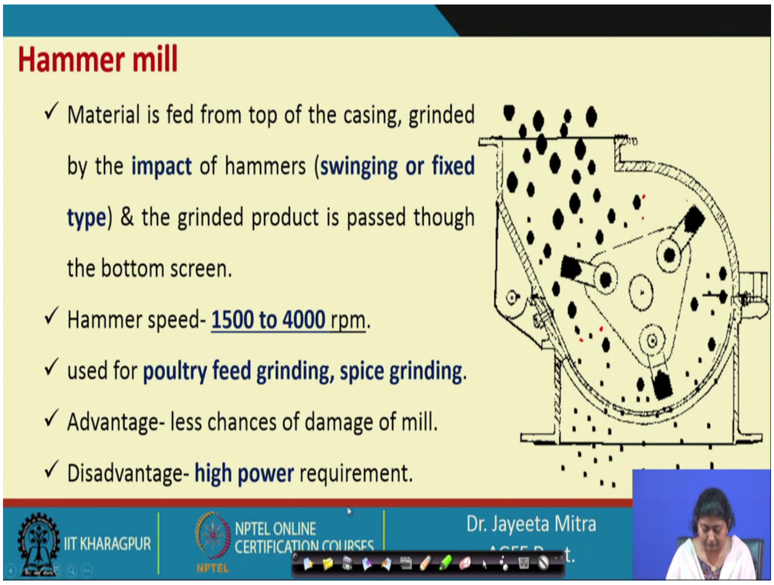

Now, next we will see the hammer mill. This is another size reducing equipment. So, what happened in case of hammer mill; the material is sent from top of the top of the casing there is a sometime there is a upper system also, on to control the flow rate also we can design the feeding system. So, from there it is coming and grinded by the impact of the hammers. So, the hammers will be maybe swinging form or may be fixed with the rotor that is moving. And the grinded product is passed through the bottom of the screen.

So, if we look into the diagram. So, the product is coming from this upper section from the top section, there here the blades are attached ok. So, this may be swinging or that is there freely moving at a pivot point or they are fixed to it, ok. Now, when they are hitting the material, they are giving an impact force on that; then they will grind and at the bottom there is a perforated tray by which the particle which are lower than that 5 will pass through and which are not reduced to that much size will be there. And they will be again circulated in the in the channel unless the size is reduced to the particular size fraction c if that is attached at the bottom section.

How much speed generally we keep 1500 to 4000 rpm, and used for poultry feed grinding spice grinding, etcetera. Also this kind of hammer mill is used for the millet grinding operation. Now, advantages that less chances of the damage of the mill, and disadvantages high power requirement needed for running a hammer mill.

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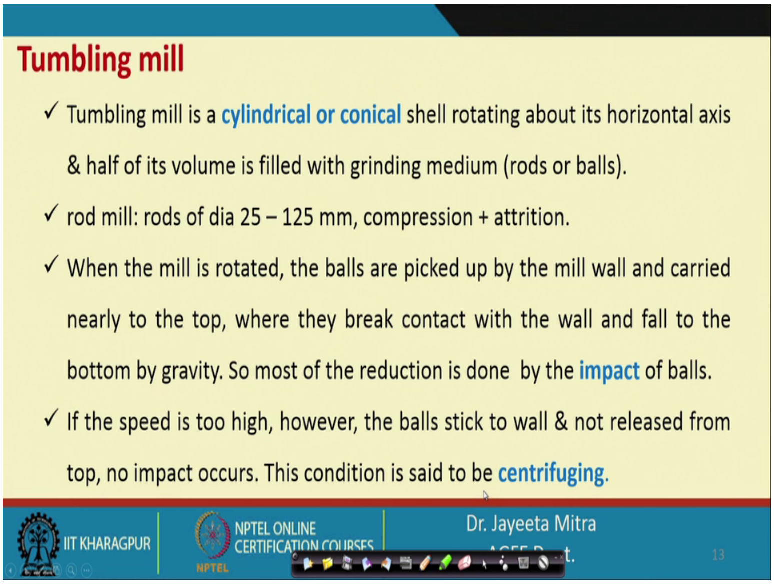

Now, tumbling mill, tumbling mill is a cylindrical or conical shell, rotating about it is horizontal axis. And half of it is volume is filled with grinding medium, that is rods or balls. When we use the rod mill rods of dia 25 to 125 mm, and here in case of tumbling mill, the compression force and attrition force attrition because there is a rubbing effect between the rods or the balls that has been given there inside the mill.

So, because of that attrition effect is also coming. Then when the mill is rotated the balls are picked up by the mill because of the motion rotating motion and. So, the mill valve will take them up and carried nearly to the top; where they break the contact with the wall, and fall to the bottom of the bottom of the cylinder by gravity. So, most of the most of the reduction is done by impact of the balls.

So, rod mill and ball mill that that we have seen. In case of the rod mill we have seen that compression and attrition, and when we use the ball mill we are getting the impact force along with the attrition effects. So, if you see this is kind of a this kind of a crosssectional area, we can we can view where almost half his fill with balls, ok. And as this rotated so, this balls are from the horizontal section to this upper section it is picked up, but since it is half filled and then when it rotates to the other section this balls will again try to fall down and because of that impact that the product will be grind and also the effect of the attrition.

If the speed is too high; however, the balls stick to the wall and not released from the top. So, no impact occurs for this condition is said to be centrifuging.

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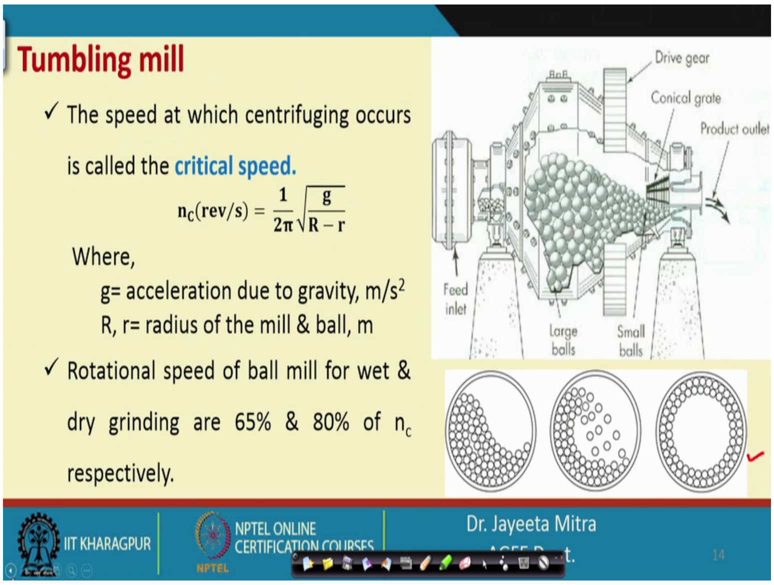

So, as I have shown you that this kind of effect is there when the speed is reasonable; that means, not very high and not very low. So, the balls will come with the rotational speed and stick to the wall up to certain extent then they will draw. And will draw they will force the impact on the product, and while moving inside they will give the attrition effects. And this is the last one is the centrifuging effect, when because of very high speed the balls are stick to the wall not coming to the bottom because of gravity.

So, this fall will take only when the force on the on the particle because of the rotational movement will be lower than the force of the gravity. But in this case the gravity force is lower than the centrifugal force that these those particles are getting. Now, the speed at which the centrifuging occurs is called the critical speed. So, here we can see in actual case how it looks like when the when it is filled with the balls, ok. This is a driving gear at the top one is a feed inlet from here we are sending the material, and this is the product outlet. There is a conical grate given and the size of the balls is also differ here the larger balls are than the smaller balls also is there.

Now, we need to we need to calculate the speed at which it should run properly. So, that is that is called the critical speed; that is denoted as n c in revolution per second is equal to 1 by 2 pi into root over g by capital R minus small r; where g is the acceleration due to gravity in metre per second square, and capital R and small r are the radius of the mill and the ball in meter. Rotational speed of the ball mill for wet and dry grinding are 65 percent and 80 percent of critical speed respectively. So, in the in case of wet grinding the speed will be 65 percent of the eta n c and for the dry grinding it will be 80 percent of the critical speed.

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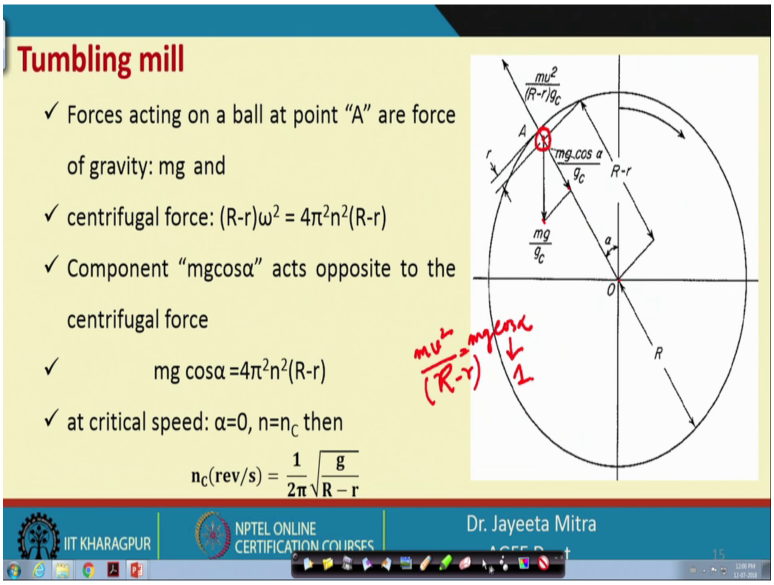

Now, we will see that how we have derived that critical speed formula. So, for that see here we have here we have a cylindrical section, the radius of r which is generating the radius of the cylindrical section. And small r, there is a small ball at the top and if you can if you can see in this is a small ball; whose radius is small r, ok.

Now, this balls are rotating ok, these are these are rotating along with the this along with the cylinder that is rotating; when it comes to the top section ok, gradually when it come to a certain section always is gravitational force acting down word ok. So, this diagram has been taken from and then everything has been given in FPS system, but you can take this as mg only instead of mg by c.

So, this is the downward gravitational force is coming, and here mv square by r that is the centrifugal force is acting on the particle which is in the outward ok. So, this particle has a tendency to go out 1 or 2 to throw it to the outward direction, based on this force and it is also having a downward force that is because of the gravity. Now, if we split the force in if it makes an angle with the line joining the centre of the mill to the centre of the particle. So, the angle it will same, later say this is alpha. So, we can we can divide this force m g to mg cos alpha and sin alpha. So, mg cos alpha will be just opposite to the centrifugal force ok. And the distance from the centre of the mill to the centre of the ball will be capital R minus small r.

Now, centrifugal force is omega square r. So, omega square R; is here R will be capital R minus small r, because that is acting on this particle at this distance ok. So, omega equal to 2 pi n so, we can write 4 pi square n square into capital R minus small r and component of this gravitational force which is mg cos alpha acts opposite to the centrifugal force ok. Now, they will be one situation when this will this will come further in this direction these 2 forces are equal.

So, if we consider that; that means, there will be alpha is equal to 0 degree so, cos alpha is 1. So, when this further goes to they towards more right. So, then a condition will arise where alpha is 0. So, we can take straight away mg cos alpha equal to 4 pi square n square into capital R minus small r, and at that condition it will be a critical speed. N will be n c that is critical speed. So, n c will then we can we can get out of this 2 equating mg with 4 pi n square capital R minus r.

So, mg with mv square r so, then we are getting mb square by r. So, then we are getting the critical speed n c has this way. So, basically what we are doing we are equating that mv square by r with mg cos alpha; where cos alpha is 1, because alpha is 0 we are considering. So, here this r is actually capital R minus small r. Because we are we need to take the centre of the mill to centre of the ball. So, this is how can calculate the critical speed of the ball mill. So, we will stop here and we will continue in the next class.

Thank you.