Fundamentals Of Particle And Fluid Solid Processing
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Lecture – 45
Particle size reduction (Contd.)

Hello, everyone and welcome back once again to the another class of Fundamentals of Particle and Fluid Solid Processing. And, we were discussing about the size reducing equipments or the comminution equipments.

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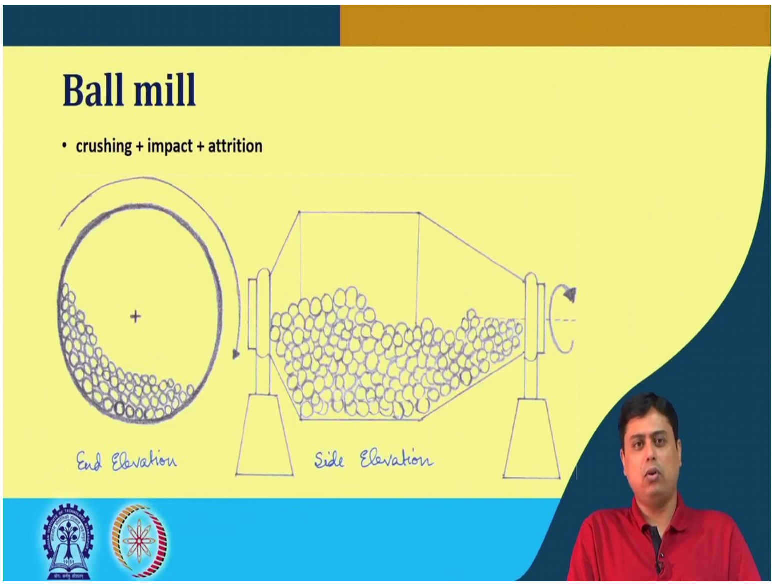

And, we will now focus on to one of the most important milling equipment is called the ball mill. We had seen in the last class this introduction that what is a ball mill and how it is operated.

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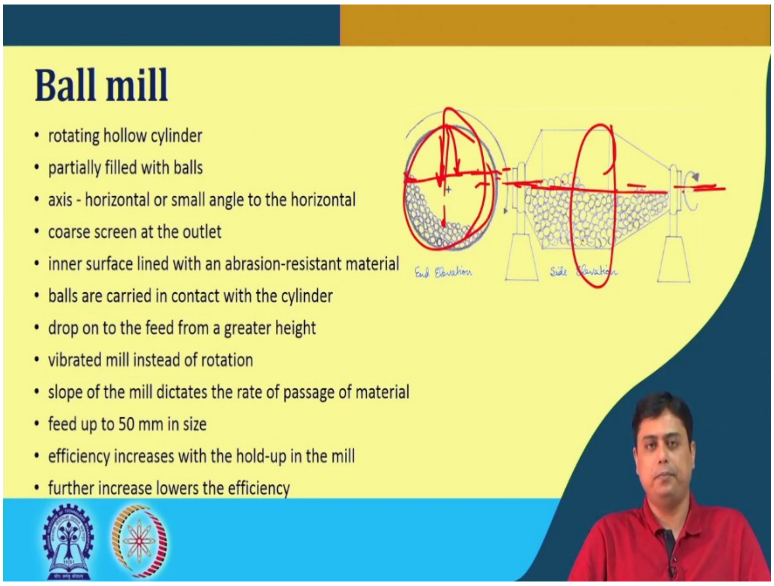

So, here this ball mill is typically consist of a rotating hollow cylinder that is partially filled with balls and its axis is horizontal or it can have sometimes some angle to the horizontal. The reason we will see. So, that means, this is our horizontal plane. So, it can be perfectly horizontal to this line or it can have a certain gradient.

So, typically we have the screens at the outlet to have this desired sizes of the product of smaller than this screen and this inner surface of this ball mill or the rotating chamber are typically made of abrasion resistant material because we can understand this balls are actually tumbling with one another. So, this balls that are half filled or say partially filled in this chamber is creating a lot of chaotic movement inside the bed and also when it come the feed is there the such load it is handling and with its rotation of this body there are heavy chances of abrasion to this all the parts of this ball mill.

So, typically the material of construction or particularly the inner lining of this rotating body is made of abrasion resistant material such as say the rover stainless steel materials. Now, it also has to be remembered that this inside wall and the ball this materials should have a high friction of coefficient. So, this coefficient of friction should be such that it the part the balls can stay in contact with the solid ball or the this rotating wall so that it can go to the up most position or at the maximum level and it can fall from there.

So, it has to drop on the feed from as great height as possible because then we have the full efficient impact mechanism that can act on the solid particle. Sometimes this mill is vibrated instead of rotation. So, instead of this rotating ball mill nowadays there are some popular applications of applying such kind of mill containing the balls inside in a vibrating motion. Now, the slope of this mill the reason I mentioned here that it can have some angle it actually dictates the rate of passage of material. It increases the capacity of the equipment. If the slope is such that the material can clearly pass through at its ease as it crushed at a time.

Now, this equipment this ball mill can handle the feed up to a size of about 50 millimeter in size and it efficiently works when the hold-up of this mill is increased; that means, the feed that comes in the void space that was created in between the balls is completely filled that is the hold-up, the void space that is being created by this random position of the balls that are already there in the mill. So, if the feed can occupy those positions effectively then this works in a most efficient way.

Now, if you increase the feed throughput more than that then the efficiency decreases because what will happen; we will see that if we increase this level of feed this particle effectively has to fall of this ball has to effectively fall on the particles. Now, if it is filled till half of the (Refer Time: 06:31) or half of the this section then this much impact will not be there or we can say that is the cushioning effect will be there. The impact will not be that much forceful what could have been in a most travel path by that ball.

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So, this ball diameter can vary something in the size in between 12 millimeter to 125 millimeter, different sizes of the balls are apply are used here. So, the optimum diameter of these balls are typically proportional to the square root of the size of the feed and this proportionality constant; that means, when we say the optimal diameter of the ball is proportional to the square root of the size of the feed. So, this proportionality constant is a function of the nature of the material.

Now, I repeatedly mentioned that this ball mills contains different sizes of the balls that is advantageous because the large balls actually influences or effects the size distribution for the feed or the coarser material in effective way. So, when the feed is the most coarse material and the product if I say is the most finer material, then the large balls actually impacts crashes the coarser feed in a most efficient way and the smaller ball handles or influences into the size reductions for the finer particles.

Now, with now we can understand this balls are going through some vigorous movement inside the ball mill. So, naturally there will be huge amount of wear and tears of these balls and then it is not uniform as ideally it should be because we can understand that by this construction the movement of this periphery would be different in different location or the velocity would be different and so, the wear and tear will not be uniform for all the ball.

So, even if we start say with the uniform size ball it will be of different size after several operation due to this wear and tear and that is helpful just because the thing that we are mentioned that with different sizes this effective grinding can happen, and that is why there are uses of compound mill or compound ball mill. Here what happens is that say this ball mill which is a single compartment is divided into multiple vertical compartments with a vertical wires.

Now, in this vertical chambers these are separated by say the wires of different sizes, say screens of different sizes. Now, as it creates are the chambers the stage wise chamber I can say each chamber contains different size of the balls or each compartment contains different size of the balls. So, starting with the feed position, there will be say the coarser balls are there or the bigger balls are there and near the discharge location near the product discharge locations we have very small balls.

Now, here in this compartment this can be of uniform size and it can gradually decrease in size from feed to the product size. So, there are two scenario; that means, one is that you take a single compartment and you use different size of balls in that or the other scenario is that you choose different compartments or you make different compartment in the ball mill by vertical screens, and in each compartment we use uniform size balls that starts from bigger size to smaller ones from the feed to the product direction.

In this way by this multistage operation we can have economical operation and uniform product. We can also improve the residence time distribution with such multistage operations because of these vertical screens; otherwise, in single stage operation what could have happened it is a kind of a one stage process that assumes that this is of uniform product. But here you can control the discharge from this compartment to the other compartment by placing appropriate size screen.

So, which means the particle sizes that has been crossed in this chamber or say the coarser particles the discharge from this one if that size is not that of the screen size or lower than. That it cannot pass through and it would be retain in that chamber 1 or compartment 1 until and unless that size is obtained, and by doing so, we can have a uniform product and its size distribution.

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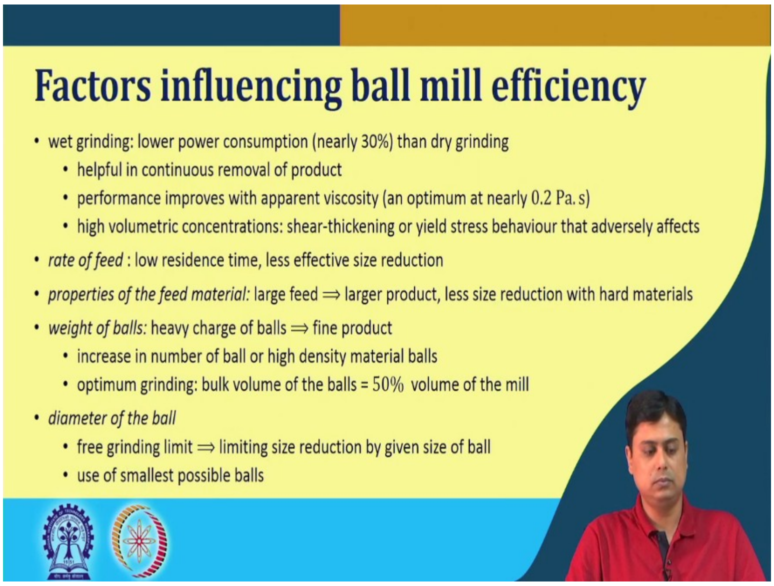

There are several factors that influences the ball mill efficiency. Now, in order to reduce the power consumption one of the popular way to operate this ball mill called we called the wet grinding or the operation with some liquid. So, here instead of say here we need some liquid phase to flow this feed as in terms of suspension. So, instead of air, now in wet grinding we have say water as the medium. And in that case the power consumption goes down by nearly 30 percent for a particular operating condition for a particular system.

Now, this wet grinding also helps in continuous removal of the product because there is a bulk motion of the fluid. Its performance improves with the increasing apparent viscosity up to nearly 0.2 Pa.s that is the optimum value you can obtain there. Now, as we increase the volumetric concentration of the feed the suspension can behave as shear thickening fluid or liquid or yield stress liquid and then it adversely influence the performance of the ball mill. So, there is also a critical concentration level of the suspension.

The important factors so, we can understand is the rate of feed in the ball mill that influences its efficiency because with the rate of feed you can control the residence time of the feed, the amount of time it would be retained in the in the chamber, so that the crushing and grinding can happen inside the chamber. If it is increased, then there will be low residence time and less effective size reduction. So, with the high throughput you can increases capacity, but there would be lesser effect of the size reduction.

The properties of the feed material is another important factor; if we use large feed there will be coarser product, less size reduction of the hard materials can be achieved if you use hard materials. So, the quality of the feed is important. The important factor is also the weight of the balls. We need basically heavy charge of the balls on the feed or the particles in order to obtain fine products.

Now, this heavy charge or the collection of the charge of this balls can be done I mean increased in two ways – one is if you increase the number of balls or you change the material of construction of this ball with the high density material. There is an optimum grinding limit that can be obtained and that can be obtained when this scenario is there that the bulk volume of the balls is nearly 50% volume of the mill. If you exceed that the grinding limit of this ball mills decreases, the efficiency decreases.

So, there is the volume restriction, by keeping that sometimes high density materials are helpful in increasing this charge of the balls. The diameter of the ball is also an important parameter because for a given size of balls there is a limitation on the size reduction ratio that is called the free grinding limit. The atoms should be made to use the smallest ball as small as possible.

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The slope of the mill we have discussed this that the capacity increases, but it results in the production of coarser product because the residence times goes lower. Discharge freedom; that means, the how easily you can take out the product if that is smooth enough it has the same effect that of the slope, if the discharge comes out quickly; that means, the residence times is lower. So, there is less significant size reduction.

The level of material in the mill we have also discussed. So, low level of material in the mill there is definitely low power consumption. Now, this can be adjusted by placing some suitable discharge opening. Even if you say operate with high throughput in order to maintain this low material level, we can have a suitable discharge opening. Because, this cushioning effect that I have discussed it increases with level, as you increase the material level there is a shorter distance the impact can happen. So, all the power that you put in is wasted in excessive production of coarser material.

The speed of the rotation of the mill is not the last, but one of the vital component because this whole operation is based on this criteria. This effective operation of a ball mill is based on this criteria that the ball will be in contact with the solid ball, it goes to the up most position and then it would fall if that happens that is the ideal scenario. So, at low speeds of rotation ball rolls over on another at if you increase the speed a bit higher the balls are thrown at short distance. If you increase it in a higher speed that distance of travel increases. If you increase it a very high speed the balls will be in contact with the wall because of the centrifugal motion and the force balance it will not be coming down from its utmost position.

So, there is a critical value of this speed.

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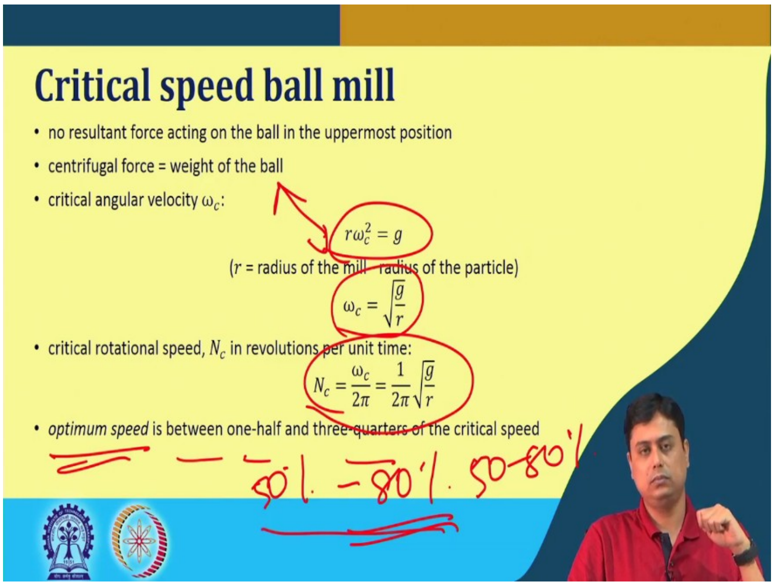

And this critical value; that means, there would not be any resultant force that should act on the ball at it is up upper most position; that means, they are the centrifugal force is equals to the weight of the ball and then it can fall. It has to be slightly lower than that in order to fall.

So, the critical angular velocity, if that is say ω_c, we can write

$$r\,\omega_c^2 = g$$

where this r is the radius of the mill minus the radius of the particle. So, that means, we can have a critical angular velocity value.

$$\omega_c = \sqrt{\frac{g}{r}}$$

So, the critical rotational speed N_c revolution per unit time can be written in this way

$$N_c = \frac{\omega_c}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{g}{r}}$$

But remember this is the critical one where the centrifugal force is just weight of the ball; the optimum has to be lesser than that so that it can drop from that uppermost position. And, in practice it has been seen that this optimum speed is something between 50% to 75% of the critical speed. In some text book they also proposed from 50 to 80% also. So, in general we can have a range of 50 to 80% of this critical speed.

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So, there are several advantages of ball mill because we have seen it can be operated in wet or drying dry grinding scenario. It has a very low cost of installation and power consumption because it revolves at a very low speed, the it can be applied under inert atmosphere because that inside chamber is basically enclosed that this whole chamber can be operated under inert atmosphere which is beneficial for handling or crushing explosive materials in absence of air. The grinding medium is cheaper, the balls can be constructed of cheaper materials, but it should be strong enough to withstand the wear and tear.

It is suitable for materials of all degrees of hardness that is why one of the parameter is there ah. There are different sizes of the balls. It can be operated on batch as well as in continuous operation. It has the flexibility in order you have the whole material charged once at a time and take the discharge out or it can be operated in a continuous scenario preferably like that happens in the wet grinding scenario.

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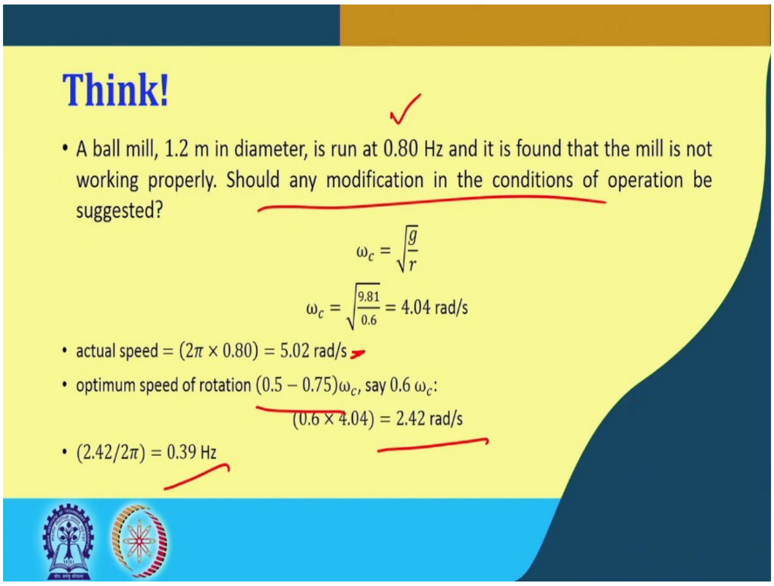

If you have to think about this operations that have that is discuss say a ball mill of 1.2 m in diameter runs at a frequency of 0.8 Hz and it is found that the mill is not working properly. So, is there any modification needed? Can you suggest something? These two information basically gives us an idea that it is talking about something about the critical speed that we have a known diameter and it is operating with a certain angular velocity, but that velocity is not enough and that is why it is not working properly. So, is there any modifications that is needed.

$$\omega_c = \sqrt{\frac{g}{r}}$$

$$\omega_c = \sqrt{\frac{9.81}{0.6}} = 4.04 \text{ rad/s}$$

So, let us look at the angular speed, we know this expression. So, currently the angular speed is 4.04 rad/s. Now, that translates to the actual speed of 5.02. This actual speed we have it from 0.8 Hz. This is the actual speed and this is the critical one that is why it is not working properly, because the actual speed is quite higher than the critical speed.

So, what should be your suggestion? Your suggestion should be that say we have to reduce this speed, but how much. Now, the optimum speed we have seen that it varies in this range that 50 to 75% of the critical speed, so, we take 60% of that. So, 60% of the critical speed is 2.42 and the actual speed is basically 5.02. So, basically we have to make a half of that actual speed in order to have a optimum operation of this ball mill. And, if we convert these two in frequency we get 0.39 Hz and it is currently running at 0.8 Hz. So, nearly it is operating currently at its double frequency, it should be half and then it can operate smoothly.

So, which means we have seen today that different types of equipment based on the stretching mechanism and particularly we had focus on the ball mill because of its popularity we have seen what is critical speed of a ball mill, why it is advantageous, why it is having void spread application and how the optimum speed can be obtained from this critical speed. So, and that brings to the end of this size reduction section and in the next class, we will see the another new section. Until then I thank you for your attention and we will see you in the next week.