Introduction to Mineral Processing
Prof. Arun Kumar Majumder
Department of Mining Engineering
Indian Institute of Technology, Kharagpur

Lecture – 25
Grinding (Contd.)

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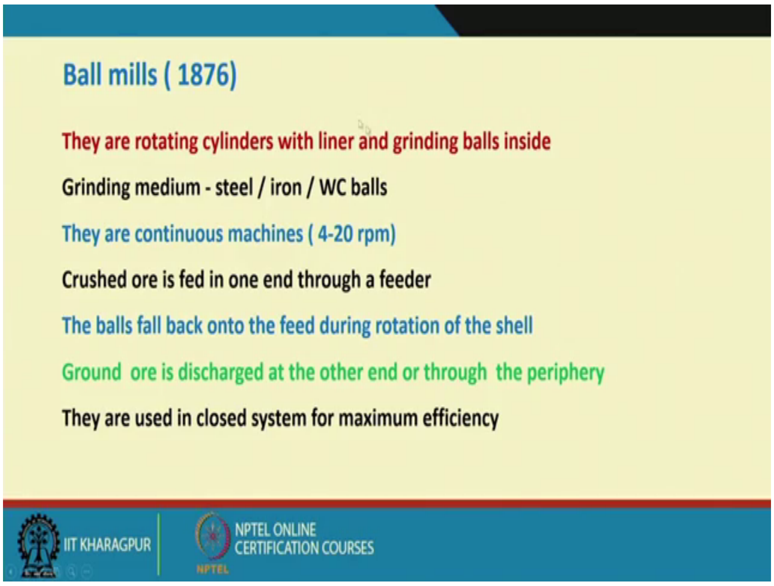

Hello welcome. So, we are discussing about the ball mill and we will continue that topic, because it is a very important piece of equipment in the combinational circuit in any mineral processing operation. So, ball mills were invented in the year 1876. And as I said that they are rotating cylinders with liner and grinding balls inside. And grinding medium can be made of steel, made of cast iron, may be tungsten carbide balls. And they are mostly the continuous machines, they are basically in a continuous machine, they tumble continuously and they try to grind the material continuously. And the rotational speed is around 4 to 20 rpm, but there are some relationship with your say dimension of the mill and what should be the rpm, we will try to do those calculations later on.

So, the ore to be crushed its fed in one end through a feeder, the balls fall back or to the feed during rotation of the shell we have shown it that it falls back. And ground ore is discharged at the other end or through the periphery, so that is called the periphery discharge peripheral discharge. So, how the material will be discharged that is also a critical issue that is it will control, it will determine that what is the residence time you can get, you can give to a ball mill.

Or conversely I can say that that will determine that your what is the capacity of that mill, because material coming in material going out there will be some accumulation. And then the material going out if it is to slower than my material going in then the rate of accumulation will be going on will increase and then you have to reduce the fresh feed contained, so that my mill say the quality of my product does not get deteriorated. They are used in closed system for maximum efficiency; they are normally used in closed system that is ball mills are generally used in a closed circuit operation for maximum efficiency.

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These are some of the pictures I can say that some of the ball mills, this is a your ball mill which is being used in an industry. There is an industrial scale ball mill although it is very small in size. This is also another that is the R l by d ratio can be anything. So, that depends on what is the purpose of that, and how much of residence time and what kind of material you want to feed that will dictate that what should be the length to diameter ratio. This is where I wanted to show that this is how the balls they fall back onto the toe we call it toe, where it falls back, and hit the particles and that will break the particles.

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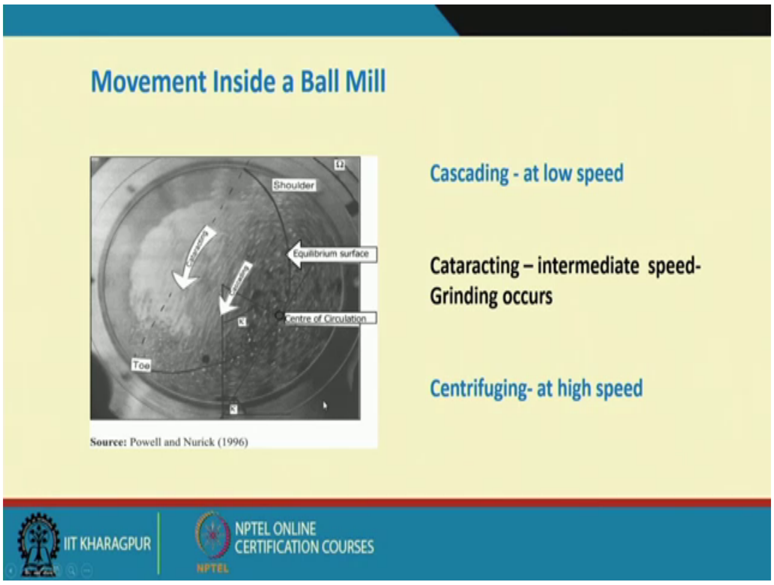

So, this is the picture, this is the image I have taken it from a paper written by Malcolm Powell and Nurick in 1996, where they captured some photographs of the movement inside a ball mill. So, what happens these are the general different terminologies we use for different sections in a mill in a ball mill. So, it is the basically the solder that is from where the most of my materials they fall back during the rotation. And this is called up your cascading action that is when it is traveling up it is going up the entire your charge that is called the cascading action. And when it is falling like this, so that is called the catalytic action. And this is the toe where it falls the entire material they fall.

And this is the center of circulation, so it has got a parabolic path near parabolic path and this is the equilibrium surface where the basically where the forces acting on particle and the acting on different particles they are in equilibrium. So, cascading, so if I want to have more of cascading effect we have to operate the mill at a low speed, because if it is at low speed then there will be cascading action so that means, I am giving more chances for breakage of the particles due to abrasion. Now, when you need when you want finer products you try to rotate the mill at a low speed because the cascading that is the abrasion it helps in fine grinding.

Cataracting, it is your intermediate speed grinding occurs because if the mill is rotated very fast. So, what will happen because of the centrifugal forces all the materials will adhere to the surfaces of my ball mill inside. So, no particle will fall back and there will be no grinding, everything will be rotated along with my mill liner and everything. So, there is a limit that beyond which you cannot rotate the mill; otherwise because of centrifugal force all the material will start rotating or even if your ball starts rotating along with the mill if it does not fall back and hit your material surfaces materials then there would not be any grinding. So, if it is too low, you will be generating a very say fine particles.

So, you have to select that what is the rpm based on the your product quality what you desire based on the material what you are trying to grind, and based on the design of your mill. So, and at high speed that is why I have written that it will be centrifuging there would not be any grinding. So, cataracting is the intermediate speed that is the grinding occurs. Now, these are all qualitative that low speed, high speed and in between speed, but there are some relationship we can always develop that what is the maximum limit of the speed. So, just bear with me, I will come to that point very soon.

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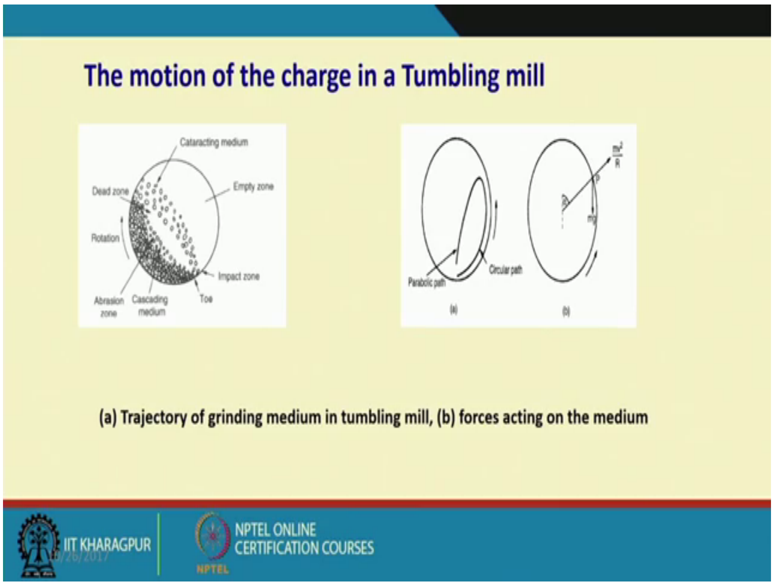

Now, if I look at closely, the motion of the charge in a tumbling mill basically you will see that it has got a first initially the circular path because of the centrifugal action. So, all the charge entire charge well we having will be having a circular path because of the centrifugal force. Now, when it reaches a particular point then your gravitational force will start acting that is your body force will be more dominant; f the centrifugal force is weaker in nature. So, because of that the material will try to fall back, so that is why you have got this parabolic path. So, beyond a point that is you have a parabolic path of this material, but this is not the entire charge that is how it is following.

So, initially maybe your entire charge may be following this, but your particles which are having higher mass mostly the grinding media. So, because the centrifugal force as I said m v square by R. So, m is more. So, it may travel up to here and that may fall like this and the material which you try to break they may fall here. So, this ball will then heat the material and then will try to break them, so that is how this being done that is you are grinding occurs.

Now, if I look at your say schematic of that, so that is the zone where you have got maximum impact that is called the toe and this is the cascading medium that is when it is traveling up when it is going up the entire charge and this is the average in zone and because of the slow rotation. And when basically the gravitational force starts becoming very dominant, so they try to fall back here, so that is called the cataracting medium; that means, cataracting medium means they are traveling, they are hitting the ball hitting the particle the bigger particle hitting the smaller particle and the particle also gets broken because of the impact at this zone. So, this is called a date zone in between this circular path and parabolic path, there is no breakage here and this is the empty zone, where you have no breakage you have no particle level no ball even, so that is the empty zone.

So, you see that inside a mill when the entire mill volume is not being utilized for my breakage of my particle, so that is why for a given capacity you need a much larger volume of the mill for this breakage. Now, here if we come back to this, if we look at your forces acting on the medium, so suppose I have got a particle was mass is m and it has reaches it has reached a point p and at that point if I do a mass balance or if I do a force balance. So, what will happen. So, at that point the particle whose mass is m, the centrifugal force acting on that is m v square by R, where m is the mass of that particle again mass is a function of your size at density because m is equal to density into volume.

So, volume into density and volume is a function of again particle size, so that is the diameter. So, m and then v is the velocity that is at what velocity you are basically it is moving and then R, R is the your orbit of radius. So, what is the orbital radius. So, that is called the m v square by R. Now, this particle will be held here if the two forces to opposite forces acting on that particle they are just balanced. So, what is this force. So, if I have an angle, if I draw a straight line from here that is a point p to the center of this your circular your section then it will have an angle alpha. And that your force we can write that is this is the m g because of gravitational force it will try to go down, but this certificate force will be counterbalanced by this mg cos alpha. So, what we can write that is m v square by R is equal to m g cos alpha because if this is alpha, this is also alpha, so you can write mg cos alpha.

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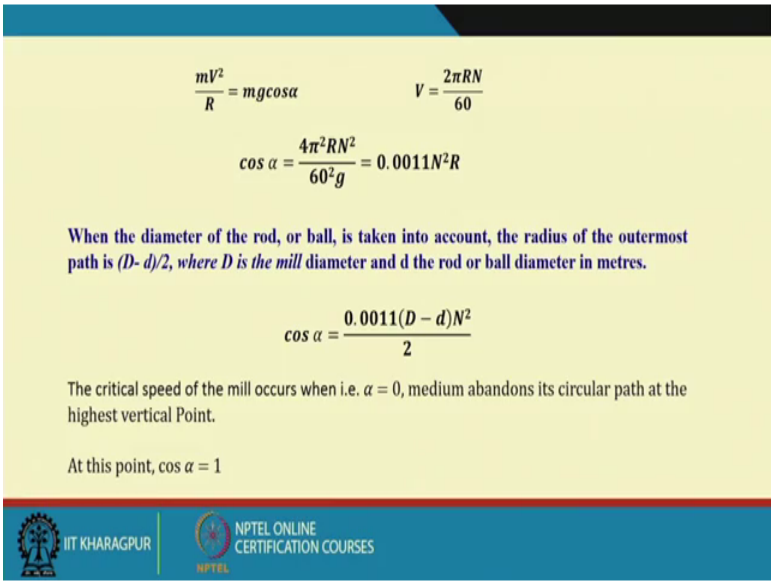

So, that is m v square by R is equal to mg cos alpha and what is the v here what is the velocity it is 2 pi R N where N is the rpm. So, rpm means is the revolution per minute. So, we have to get it right to the unit of second. So, we can write V is equal to two pi R N by 60 because N is the rpm revolution per minute. So, it is cos alpha I can write is equal to your m v square by R divided by m g, so m, m gets cancelled out. So, it is V square by r g. So, we can write 4 pi square R N square divided by 60 square g because what will happen that V when we are writing it is V square. So, it becomes 4 pi square R square N square 60 square. So, that R square by R becomes R, so we get these their cos alpha is equal to 4 pi square R N square divided by 60 square into g, g is the gravitational acceleration term.

So, if I put the value of g the gravitational acceleration value, so we get a relationship of 0.001 N square R. Now what is this R, because the R could be the diameter of my mill, but effectively what happens you also have the bigger balls? So, you have to subtract that diameter of the bigger balls from the your diameter of the mill. So, for the diameter of the rod or ball because you can use the instead of in place of your ball, we can use the rods also that we will discuss. So, then we call it a rod mill, but say for this case when we are discussing about ball mill. So, for the diameter of the ball is taken into account if you take into account the radius of the outermost path what is the maximum path that is the outermost path that is the dimension that is the diameter of that.

So, is the D minus d by 2 because radius is half of the diameter, so D minus d by 2, where D is the mill diameter and d the ball diameter in meters. So, if I replace this what I in this equation what I can write that cos alpha is equal to 0.0011 D minus d N square divided by 2. So, this is through force balance we can derive that is cos alpha is equal to 0.0011 D minus d. The capital D is the diameter of the mill, and small d is the diameter of the ball or the grinding media, N square, N is the rpm at what speed that is rotated divided by 2.

So, now, if I go back to this slide when the alpha is equal to 0, so what will happen. So, everything will alpha is equal to 0 means it goes there. So, it will fall back so that means, it is being rotated the entire thing. So, when the alpha is equal to 0, so the critical speed of the mill occurs when alpha is equal to 0 that means, the medium abandon its circular path at the highest vertical point, because when if the medium that is the entire charge it abandon its circular path and then starts falling from here like this. So, that is the maximum speed we can have and that is called the critical speed.

So, we want the material to abandon we want the medium and the particles to be broken that they should abandon its circular path and follow a parabolic trajectory beyond is up to after reaching a certain height because otherwise if it goes up to there and it falls back then there would be no grinding. So, that is called a critical speed of the mill occurs when alpha is equal to 0, so that means, this is equal to 1. So, the medium abandons its circular path at the highest particle point at this point cos alpha is equal to 1.

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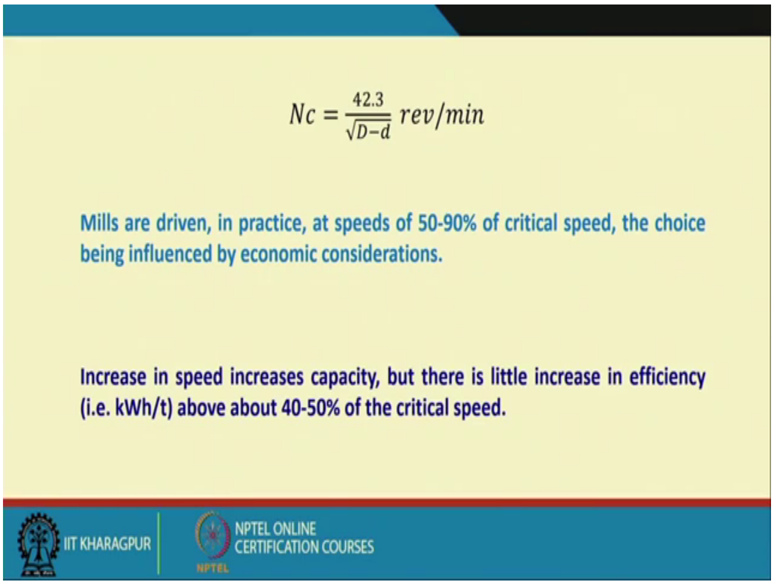

So, if we put this value cos alpha is equal to one we can write that what is the maximum rpm that is N c square is equal to we if we just simplify that we can see we can derive at in c, c stands for critical. So, the critical rpm or the critical speed is equal to 42.3 divided by square root of capital D minus d and this is the rpm. So, my mill should be operated that is the maximum limit up to what rpm my mills should be rotated because otherwise if you operate the mill beyond the critical speed, the material will never abandon its path and then it will start rotating along with my your entire mill surface. So, there would not any breakage.

So, do we operate my mill at this critical speed no because at this critical speed that is my maximum limit. So, mills are driven in practice at speeds of 50 to 90 percent of critical speed. We normally try to use a 50 to 90 percent of critical speed. The choice being influenced by economic considerations and the product quality you require which is not written here. Because what will happen if the mill is rotated too slowly so that means my although I will be generating much more finer particles as I had discussed already because your cascading action or the abrasion will be much more dominant.

But your mill capacity because that at what rate the material will be discharged that depends on at what rpm my mill is moving. So, if it is moving too slowly, so my discharge rate will be too slow, so the mill capacity per unit volume will be much less.

So, that means, you require more number of mills to produce a certain amount of material of that particular quality.

Now, if you run it at too high speed; that means, that 90 percentage of critical speed you may end up of relatively coarser particles, so that means, as I said that mostly they are used in a closed circuit grinding operation. So, if the mill is at a 90 percent of the critical speed, so what will happen your classifier that is your size separation device will send you back more amount of material through the underflow as a your re circulated load as recycled material to your mill.

So, what will happen my mill can accept per unit time a certain volume of material that is your input material. So, if my recycle material volume is if it is higher, so my fresh feed input will be less. So, in that case also my capacity may go down, but my quality of the product will be ensured. So, in both the cases you have to make a compromise that at what speed and at what how much money or how much of energy I should be utilizing and these are the difficult decisions or these are the challenges of a mineral processing operator or say mineral processing engineers that what should be the my optimum mill charges. What should be my optimum mill rpm or the optimum input energy to be utilized.

Increase in speed increases capacity, no doubt, that is what I said that increases, but there is little increase in efficiency above about 40 to 50 percent of the critical speed. Because what will happen if you increase too fast too much as I said that your recycle load will be very high and your stress feet your input will be less, so although your entire process may be less efficient in terms of capacity also. So, it is being practiced that at 40 to 50 percent of the critical speed the means are run or means a tumbled.

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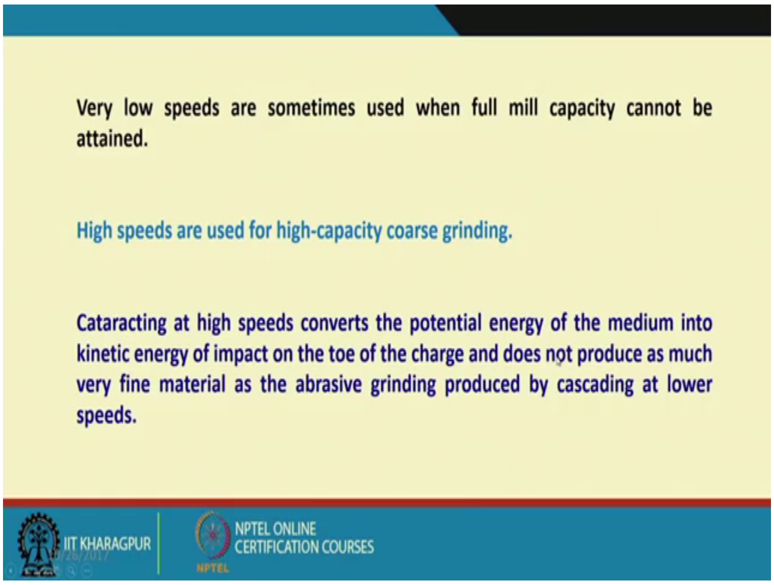

Very low speeds are sometimes used when full mill capacity cannot be attained. Like many a times I have got a mill which can accept up to which can process up to 10,000 tons per hour, but we are not getting input material at that rate we may be getting at 8,000 tons per hour. So, in that case maybe we can reduce the mill speed, so that my capacity is matched.

Because your mill operates at the best condition when it has got an optimum your say heat solid concentration aid to the inside the mill that means, there is a the proportional distribution between your ore material, your water and the you are grinding media. So, if that is altered then probably then in most of the cases the efficiency of the entire process gets disturbed. So, in that case you may have to reduce your mill or speed.

High speeds are used for high capacity coarse grinding, so that means, when you are doing it in stages like your primary grinding. So, they are maybe you can go for high speed your ball milling because there you are basically aiming at for coarser grinding because you know that there will be another secondary grinding operation where we will get my desired product by fine tuning the mill speed.

Cataracting at high speeds converts the potential energy of the medium into kinetic energy of impact on the toe. Because cataracting means when it is falling back, so that means, the potential energy of the medium it gets converted into kinetic energy in the form of impact on the toe of the charge and does not produce as much very fine part material as the abrasive grinding produced by cascading and lower speeds. I remember that we had already discussed when we are discussing about the crusher that your impact your mechanism that is your impact force, so when you utilize for breaking the particles it does not generate much of finer particle, it helps in coarser particle your size distribution as a product. So, there is a similar thing is because of the impact you may not have the your desired your fineness of your product. So, when I need a very fine particles as a discharge, so I need to reduce the speed, so that I can promote the cascading action.

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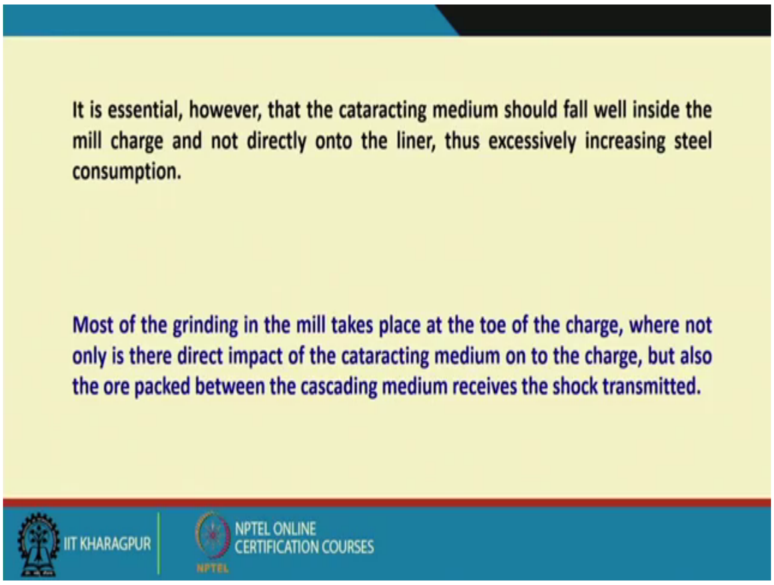

It is essential, however, that the connecting medium should fall well inside the mill charge and not directly onto the liner, thus successively increasing steel consumption this is a very vital point. That means, the my grinding medium might I should design my mill in such a way and optimize the process parameters in such a way that my grinding media they fall on top of the my particle which I want to grind. Those otherwise what will happen if they fall randomly and if they are hitting the liner material without hitting the my material - the ore, which I want to grind, so what will happen it will unnecessary say increase the steel consumption because of your wear. Because of your repeated impact of the harder material to the steel surfaces, it will generate it will cause wear as well as the grinding media as well as your liner surfaces.

So, that is not what is wanted. So, that is the designer that is the design engineers your role that is how do I design the your mill. So, that my grinding media they have a proper cataracting action, and they should hit my material directly on the toe; otherwise there will be it will be wastage of energy as well as it will unnecessarily aggravate the wearing process of my medium as well as my grind liners.

Most of the grinding in the mill takes place at the toe of the charge toe. I think you remember where the entire material is falling there is the toe, where not only is there direct impact of the cataracting media on the charge, but also the ore pact between the cascading medium receives the shock transmitted. Because what happens that it is not only that it the toe region, it is not only the impact what is occurring, but also the ore packed between the cascading medium there because it is also starting to cascade from there. So, it received the shock also that transmitted. So, because of that shock wave also the particle many times they get broken. So, my important place is that toe region.

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What are the factors that affect size of product from ball mill? Now, it is important to fix the point where the charge as it is carried upward breaks away from the periphery of the mill that means, at what point because if it breaks away at a very at a much lesser height, so the impact on the particle will be less. And if it is too much then they will fall outside the toe region, so that is very important that to fix the point where they charge as it is carried upward breaks away from the periphery of the mill. This is called as break point or angle or break, because it is measured in degrees because it is measured in degree that what angle what is that angle. It is measured up the periphery of the mill from the horizontal that if we draw a line horizontally, and then what is that angle, and that is called the angle of break or break point.

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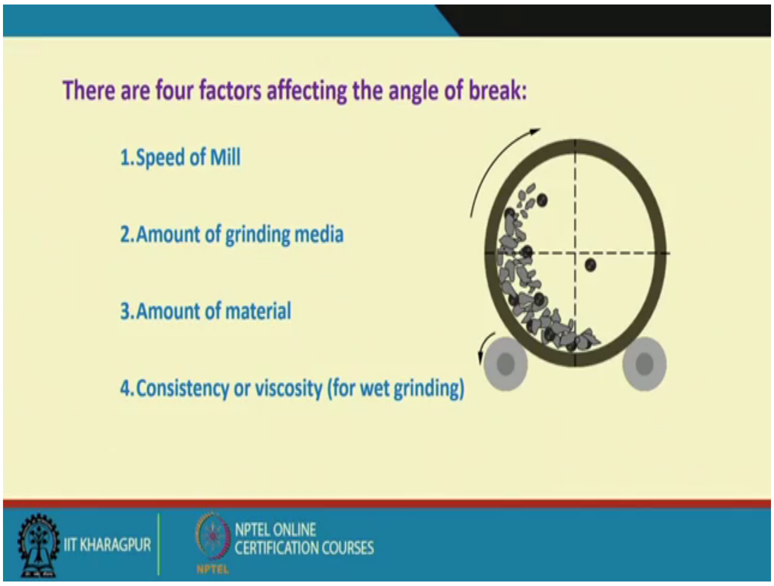

There are four factors, which affect the angle of break. One is the speed of the mill that is what we have already discussed that is your speed of the mill. Then two amount of grinding media. We have discussed about the size distribution of grinding media, but how much of that grinding media you are utilizing, so there is the amount of grinding media. Amount of material to be broken; that means, at what rate you are feeding the material. So, what is the quantity of material you want to break per unit time.

And in the consistency or viscosity for weight grinding this is very, very important because we are also adding water. So, for the and the slurry in the form of slurry the finer particles has to go out from the system. So, the rheological behavior is the viscosity related issues will also determine that at what rate my product is being discharged. If it is too slow, so it will be broken down to very finer sizes and it will reduce the capacity and it will generate much more finer particles as the discharge. So, these are the four main factors which affect the angle of break. Speed of mill, amount of grinding media, amount of material which we want to break, and the consistency or viscosity for weight grinding.

Thank you very much; we will continue this topic in the next lecture.

Thank you very much.