Downstream Processing
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Lecture - 10
Solid Liquid Separation – problems

Today we will do some problems on the same solid liquid separation problems related to filtration problem, centrifugal separation as well as centrifugal filtration.

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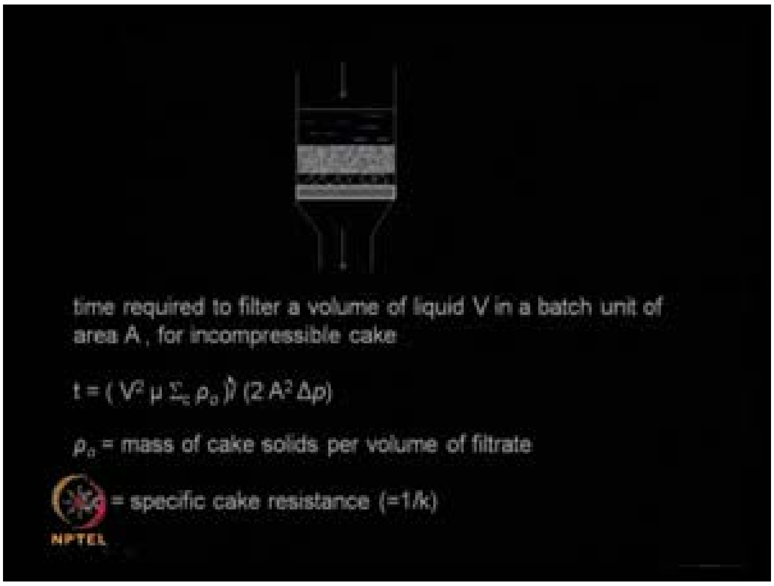

Let us recall the time required to filter on a flat bed of certain solids. So, if you recall this is the equation which we looked at and the equation was obtained using Darcys law. So, the equation says that time required to filter is function of many parameters the viscosity of the medium, the volume that needs to be filtered and it is inversely proportional to the area and the pressure drop. So, if the pressure drop is very high then time required will be less and the area is very high, time required will be less.

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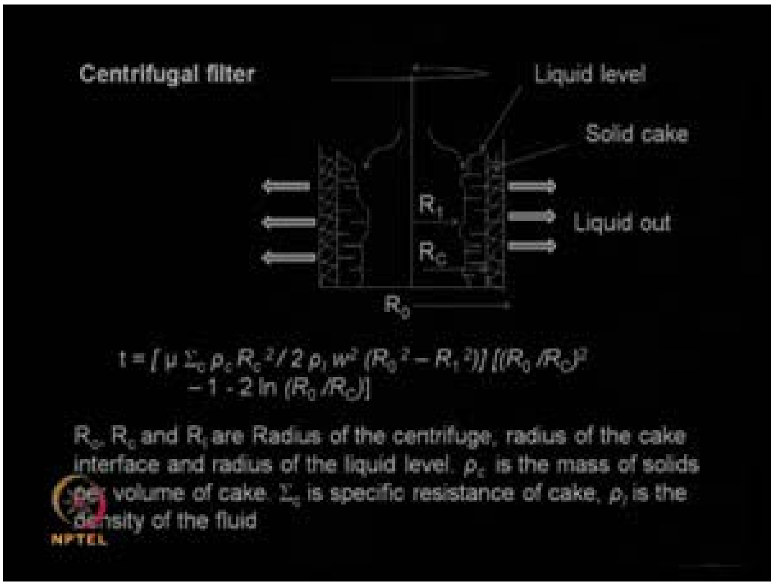

Now, similarly; you also have an equation for centrifugal filter as a centrifugal filter. I think I explained in previous classes can be used to filter solid using a centrifuge. So, this filter contains a basket, a porous basket and the cake is formed along the periphery of the cylindrical portion of the centrifuge. The liquid flows through the solid bed that formed and escapes out. So, here; the bed is in the cylindrical form whereas, in a flat filter the solid that gets deposited is plat formed.

So, that is the main difference on the centrifugal filter as well as on the flat bed filter actually. So, the time required to filter depends upon several parameters here, because it is a centrifuge we have the angular velocity of centrifuge, we have the several radii terms coming into picture. R not is the radius of the centrifuge R C is the radius up to the top of the solid bed R 1 is the radius of the liquid level. And, of course; you have terms like L which is the height of the centrifuge or length of the centrifuge and you also have the density terms coming in to the picture here.

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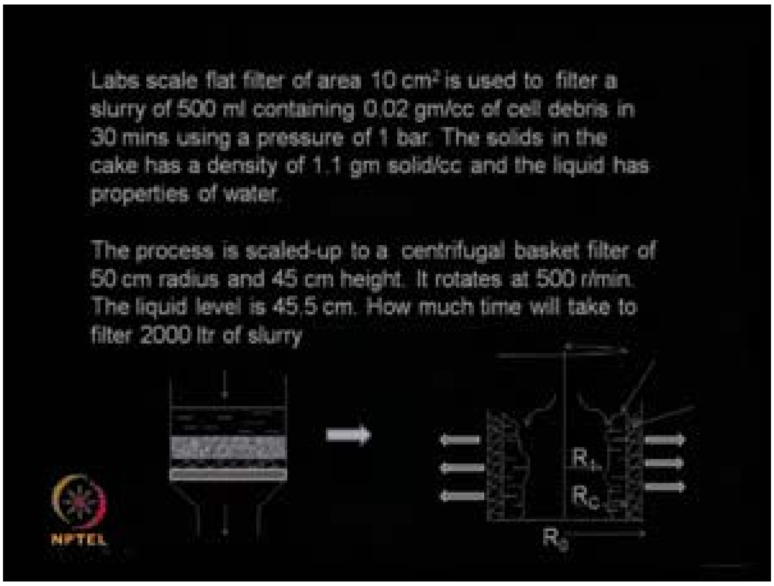

Now, let us consider the problem which involves both the flat bed centrifuge as well as the sorry flatbed filter as well as the centrifuge. Suppose, I am doing an experiment in my lab using a flat filter area is 10 centimeter square. And, I am filtering 500 ml of a slurry containing 0.2 gram per cubic centimeter of cell debris. And, I am able to achieve it in 30 minutes using a pressure of 1 bar.

Now, solids in the cake have density of 1.1 gram solid per cubic centimeter and the liquid has the properties of the water. Now, you collect the data in the lab generally, using a simple filter, flat filter like; you use you bookner funnel and put in filter cloth or a filter paper. And, then you achieve this filtration, now; you want to scale it up to a large scale.

So, you do not like to do the same operation you would like to use a centrifuge that means a centrifugal basket filter. Now, the dimensions of the centrifuge is which got a 50 centimeter radius that is R naught and it is got 45 centimeter height, that is; the length it rotates at 500 revolutions per minute. The liquid level is 45.5 centimeter, that is; this portion.

Now, how much time it will take to filter 2000 liters of slurry? So, understand I do my experiments in lab using a very simple setup a flat filter and then I want to scale it up to large scale operation, where I want to filter 2000 liters using a centrifuge. Some dimensions are given and you are asked to calculate what should be the time taken to filter 2000 liters of the slurry?

If you use this particular type of centrifuge you assume the properties of the solid to be same we move from lab scale right up to the manufacturing scale that is important .So, what do you do? You calculate the properties of the cake from the lab scale data. And, then use that and put it inside the equations for the centrifugal filter and calculate the time required. Now, many data are given for the lab scale flat filter.

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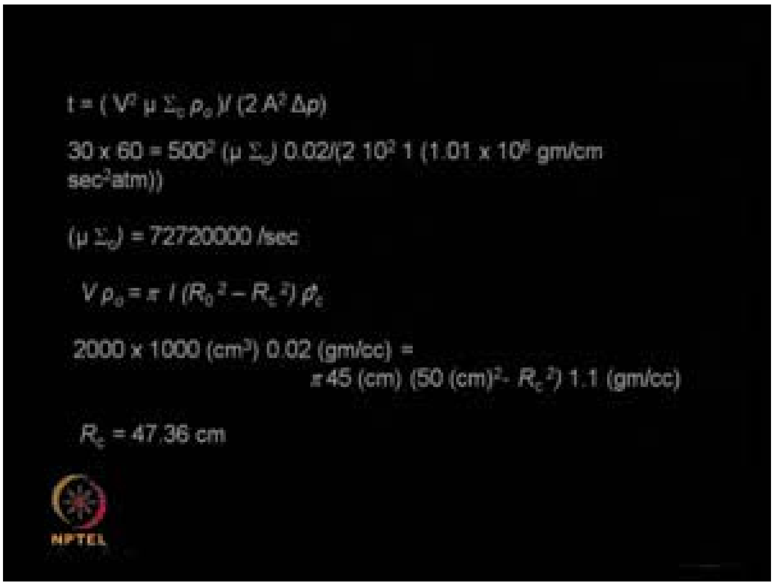

Now, if you recall again this is the equation for the flat filter the time in terms of the volume that needs to be filtered, the viscosity, the row not then the area of the filter set up and the delta P. So, it is a 30 we are converting that into seconds and then volume that needs to be filtered its 500 cubic centimeter and I put in here these2 are unknown. So, this is the unknown here, and row naught is given as 0.2.

Now, area is given as if you recall properly it is a 10 centimeter square flat filter area. So, you put in 10 centimeter square and then the delta P is 1atmosphere. So, you are converting that properly here. So, you have the left hand side, you have the right hand side the only unknown is mu, sigma C. This determines the properties of the solid, liquid. So, you can calculate from these equations this whole thing ok.

Now, we need to calculate in the centrifugal filter the thickness of the cake. So, how do you do? You can do a mass balance from this particular data set. The data that is given is wanted to filter 200 liters of slurry. And, the solid in the cake has the density 1.1 gram solid per cubic centimeter correct. And, then you know the overall radius of centrifugal filter.

So, we can do a mass balance and from there we can calculate what will be the thickness of the cake? That means; we can calculate, what will be the RC? Understand. So, you have V into O naught. V is the volume that needs to be filtered in liters. So, we can convert that into cubic centimeter and the drow naught is the density. So, that gives the amount of solid material that needs to be filtered that is on the left hand side.

Now, on the right hand side we can do the amount of solids present or the solid that is going to get a cubic centimeter accumulate in the centrifuge, this is; like pie L. L is the height of your centrifuge R naught square minus R C square that gives you the area of the cake, cylindrical cake that forms in the centrifuge you understand. So, pie into height, into area of the cylindrical cake gives you the volume of the cake that forms in the centrifuge. And, you are multiplying by the density row C which is also given. You see the solids in the cake have a density of 1.1 gram solid per cubic centimeter so, that is given.

So, that is what we are going to use it here, that is; the 1.1 cubic centimeters here. So, what you are doing is you are balancing the amount of solids present in the slurry with the amount of solids or amount of cake that deposits on the walls of the centrifuge by balancing these 2 terms. For example, this relates to the amount of solids present in the slurry and the right hand side gives you the amount of cake that deposits on the walls of the centrifuge by balancing these 2 terms.

We can calculate R C, that is; the levels of the cake were as, R naught is the radius of the centrifuge which is given as 50. So, we put volume as 2000 into 1000. So, you are converting that in to cubic centimeter and then the density is given here grams per cubic centimeter, then you have pie here. And, then length of the centrifuge is 45 centimeter, then R naught square minus R C square. R naught is the radius of the centrifuge which is given 50 centimeter. So, R C is what you do not know? And, then density is 1.1.

Now, we know all the terms except R C .So, R C is calculated as 47.36 centimeter. So, you see the thickness of the cylindrical cake that is; formed during the centrifugal operation will be 50 minus 47.36 you understand. So, that will be around 2.74 centimeter. So, 2.74 centimeter thick cylindrical cake is formed with the V row naught quantity of the solids present in your slurry. So, this equation is mass balance of the amount of solids present in the slurry with the amount of cake that gets deposited in the centrifuge when you process this much amount of slurry.

So, by doing this balance we are calculating the level of the cake, that is; what is R C? Why do you need this R C? We need this to calculate the time required to process 2000 liters of slurry in a basket centrifugal filter. Because that is not given in the problem only the radius of the centrifuge basket is given so, to calculate that we use this particular mass balance equation.

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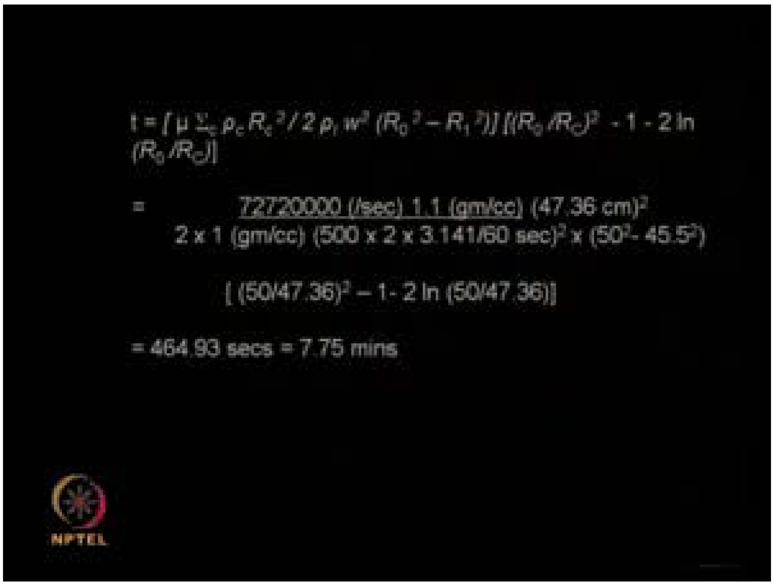

So, we go back to the equation which tells you how much time we required to filter the liters of the slurry in a centrifuge of radius R naught and length L. So, we just put in all the data here, and remember that R C is what we calculated from the mass balance, that is; 47.36 centimeter R naught is the radius of the centrifuge, that is; 50. So, by doing all this what do we get? The amount, the time required to filter so, many liters of the slurry as 7.75 minutes. So, this particular problem is a combination of both flatbed filter as well as the centrifugal basket filter.

So, you carry out some experiments using the flat bed filter. And, those data will be used to estimate the resistance offered by the cakes as well as the viscosity of the fluid. And, then we take back data put it inside the equation for the centrifugal filter and from there you calculate the time required to perform this particular operation it is the centrifugal operation or centrifugal filter. And, that is what it s normally done if you are translating data from the lab to the large scale manufacturing plan. So, in the lab you might not do the filtration operation using a centrifuge. You generally, use simple flat filter setup. And, then you apply certain, you known the area of the filter set up.

And, then you estimate what will be the? What is the time that takes to filter certain amount of slurry? And, then using the data you estimate the resistance offered by the cake and then use that to calculate what is the time required to perform the filtration using a centrifuge? So, these 2 equations are very very useful to do this type of scalar.

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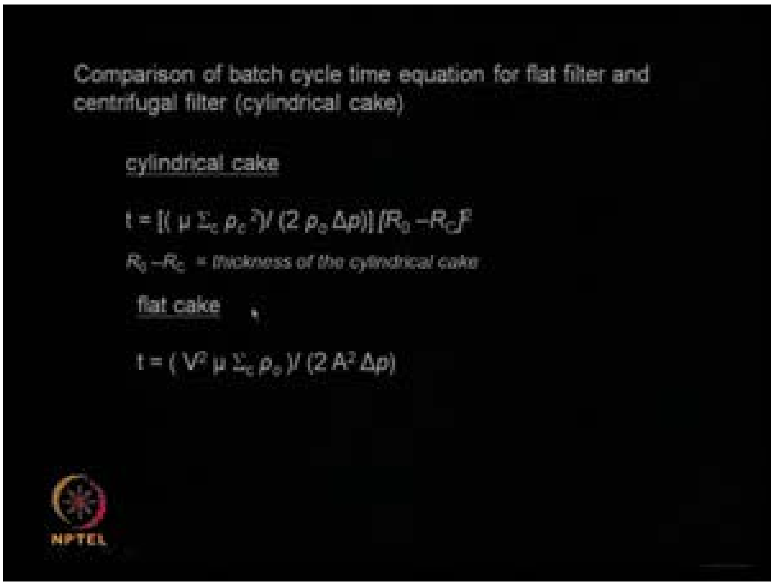

One important point which you need to remember is that when I use a flat filter the cake that is formed is flat, were as, when I use a centrifugal filter to filter the solids then the cake that is formed is cylindrical. So, there is a difference between the cakes that is formed. If I use the simple flat filter the cake will be flat. So, the equation will be like this, were as when I m using the cylindrical basket centrifuge then the cake also is going to be a cylindrical.

And, the cake will be like R O minus R C thickness, but it will be in the form of a cylindrical cake. So, the equation for the time will be like this. So, you see these 2 equations they look similar were, the main difference between these 2 equations is the cake that is formed. In a flat filter will be flat were as the cake that is formed in a centrifugal filter will be of centrifugal shape ok.

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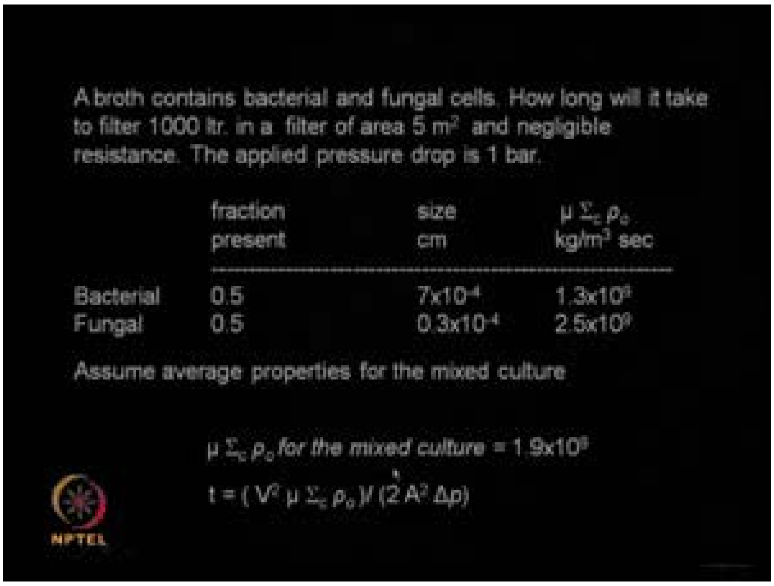

Let us look at another problem were you have mixtures of solids that needs to be separated this is very very common. You know after a fermentation broth we may have many different solids that need to be separated. So, each solid may have certain size, each solid may have offer different resistance during the filtration operation. Now, you consider a broth which contains bacterial fungal cells.

Now, we want to know how long it will take to filter 1000 liters of a broth in a filter of area 5 meter square. And, we assume that the filter medium does not offer any resistance and you are applying 1 bar pressure. Now, the bacterial cells have certain property like the size is given here, like 7 into10 per minus 4 centimeter.

And, the resistance offered by it is given here, 1.3 into 10 per 9, were as; the fungal size is different and resistance offered is also is different. And, we will assume 50 ratio of the bacterial fungal. Now, the problem state that we can consider average properties means we can take the ratios to be directly proportional to each other.

So, that means; if you want to calculate the mu sigma C row naught for this combine system we can assume an average of 4.3 into 10 power 9 and 2.5 into 10 power 9 so, that is; why it says we can assume average properties. So, the problem becomes very simple we know the amount of slurry that needs to be filtered then we take an average of this and use it here. We know that the area of the filtration setup we know the delta P that is

1bar. So, all you need to do is introduce all those terms here and calculate t so, very very simple straight forward.

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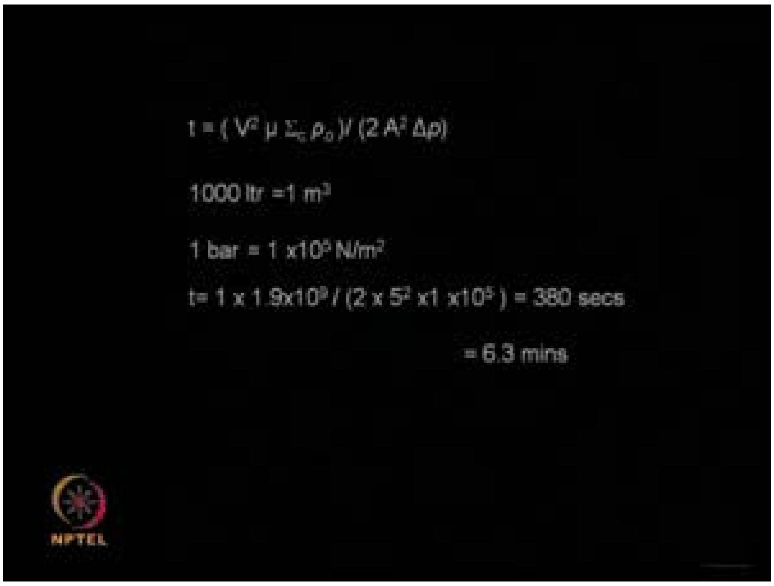

So, you get 6.3 minutes. So, it takes 6.3 minutes to filter a mixture of bacterial and fungal of equal proportions, but they have different resistivity. One important point you need to remember is you need to convert the 1 bar pressure that supplied during the filtration to Newton per meter square. So, that is very very important that comes here actually. So, units is very very important when you do problems of this nature you see we have looked at combinations of units, centimeter square, meter, Newton per meter square, bar, atmosphere pressure, liter cubic centimeter.

So, many different units appear in all our problems so, please keep note of this. And, make appropriate conversions otherwise you will end up with wrong answer do not forget that make appropriate conversions. So, this particular problem we have mixtures of 2 solids which need is to be separated and each solid has a different resistance offering and the time is found to be 6 .3 minutes.

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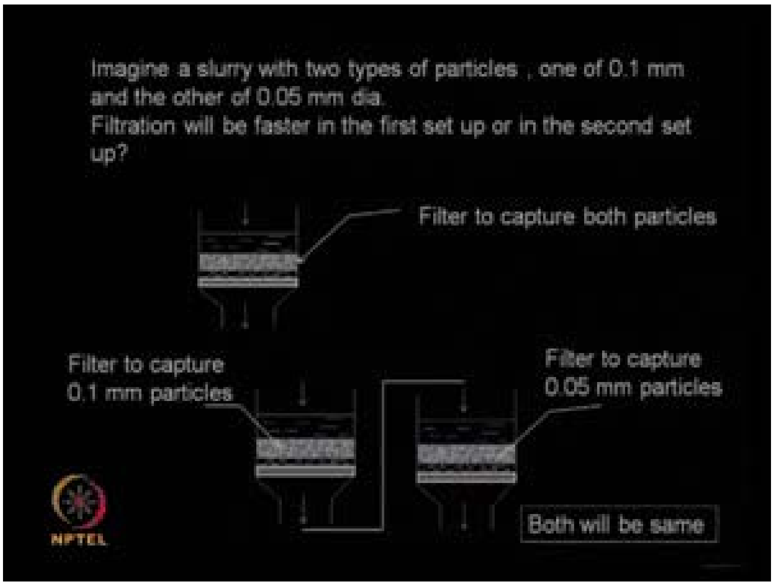

Now, let us look at the problems likely the different fashion. Now, imagine slurry with 2 types of particles you have 2 types of particles 1 of 0.1 millimeters and the other is of 0.5 millimeter. Now, suppose I consider only one filtration setup and have very fine pore. So, that it is able to capture both 0.1 and 0.5, so; pore is here are very fine. Now, consider another filtration setup 2 filters are there the first one has a very cores holes so, it will capture only 0.1 millimeter, 0.5 will pass through.

Now, this 0.5 is captured in the second filter that means; the holes are very fine. So, you have 2systems, 1 system where the holes are very very fine. So, both 0.1 millimeter and 0.5 millimeter is captured in the other place you have 2 filtration units here the holes are very cores. So, only 1 millimeter is captured 0.5 escapes which are captured in the second filter. Now, 2 systems are there now, will the filtration be faster in this? Or the filter will be faster in this? So, here we have only 1 filtration setup and capturing both 1 millimeter and 0.5 millimeter were as here,

we have the cores filter which captures 0.1 millimeter and the fine filter which captures the remaining 0.5 millimeter, So, will the filtration be faster in here? Or the filtration is faster here? Both will the same there wont be any difference why? Because if you look at the Darcys law equation the size of the particle are not coming at all into the term right please remember the Darcys law equation the terms in the equation is the amount of slurry that needs to be filtered, the viscosity of the fluid, the resistivity offered of the solid, area of the filtration unit, density of the slurry, pressure applied. But the particle size is not coming into the picture.

So, obviously; filtration does not depend on the particle size a cubic centimeter or ding to the equation actually. In reality it will have so many effects if you have very fine particles may go on block the holes. So, after some the filtration may totally stop if you have a very cores particle and fine particle the resistivity may change that it means; the resistance offered by the particle for the flow of the fluid may change.

That is why we sometimes add some filtrates? Sometimes if the particles is very fine it may even compact and it will offer certain pressure during filtration. So, in reality so many things can happen because of fine particle and vis-à-vis the cores particle. But if you look at the Darcys equation there is no mention about particle size.

So, filtration does not depend on the particle size at all. Another important parameter if you remember you might have studied in fluid flow through pack beds the pressure drop across pack beds are definitely related to the particle size. If the particle is fine pressure drop increases, if the particle are very core the pressure drop is less. You must have heard about equations like Edvans equations and so on. Which measures pressure drop across a pack bed so, there particle size plays a very very important role. But in Darcys law equation we do not have specifically term particle size but in reality particle size comes in various places. So, you should keep that point in mind ok.

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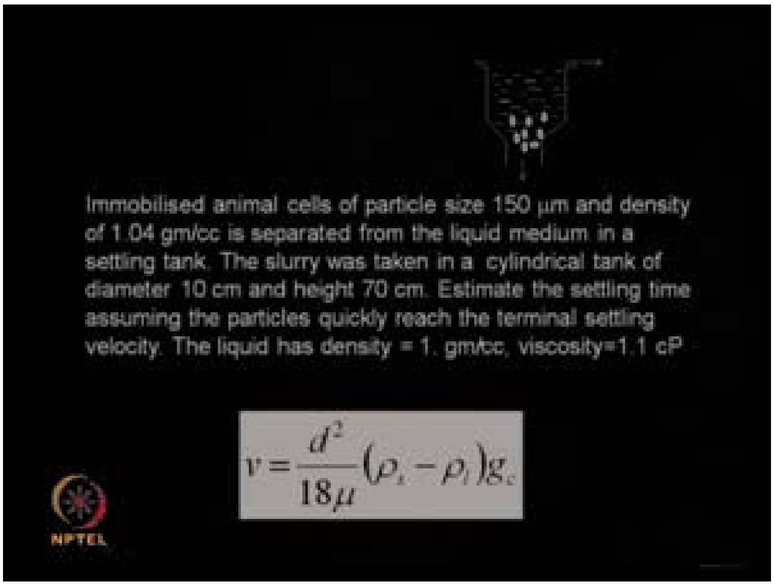

Let look at something related to settling so, you would like to perform settling operation. So, we have immobilized animal cells of 100 and 50 millimeter it is sorry, it read it has 100 and 50 micron and density of 1.04 grams per cubic centimeter. And, you would like to separate it with liquid medium in a settling tank. So, the slurry is taken in a cylindrical vessel of diameter 10 centimeter and height 70 centimeter. So, the diameter is 10 centimeter height is 70 centimeter estimate the settling time assuming the particles quickly reach the terminal settling velocity.

The liquid has a density of 1gram per cubic centimeter and viscosity of 1.1 centi poise. So, we have certain particles of 150 micron and a density of 1.04. Now, let us look at a problem related settling. Now, consider immobilized animal cell, particle size is 150 micron and it is called a density of 1.04 grams per cubic centimeter. Now, you like to separate this particular animal cell from a liquid medium, in a medium in a settling tank.

So, we would like these solids to settle down to the bottom so, that you will have the clear liquid at the top and the solids right at the bottom. So, we are doing this in a cylindrical tank so, the diameter is 10 centimeter the height is 70 centimeter. Now, I would like to know how long I should allow it so that the solids will all settle down. The assumption here is the solids quickly reach the terminal settling velocity and then the liquids has a density of 1 grams per cubic centimeter and a viscosity of 1.1centi poise.

Now, if you remember the stocks law which we thought in the previous classes the velocity that means; the terminal settling velocity arises, because of the balancing of the drag force and the buoyancy, acceleration due to gravity. So, this velocity depends upon the diameter of the particle difference in the density between the solid, liquid, viscosity of the fluid which comes in the denominator.

So, I hope you remember this equation. So, the diameter of the particle is given here row S, row l, viscosity is given here. So, we can calculate the terminal settling velocity right. Once we terminate terminal settling velocity I know the height of the tank. So, from there I can calculate how long it will take particle from the top coming down at the bottom. Because that is; what you want to calculate? You want to calculate the settling time.

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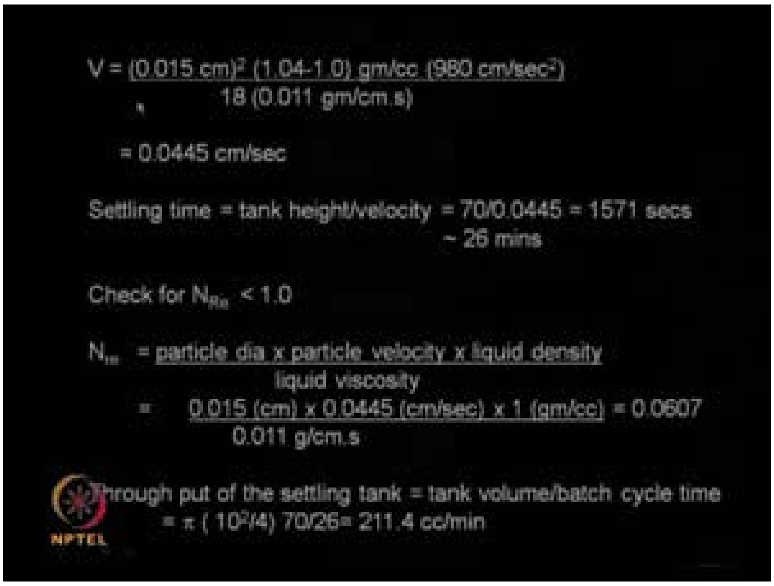

So, we introduce all the terms in our stokes equation so, we end up with the terminal settling velocity of 0.0445 centimeter per second. So, the settling will be height divided by velocity. So, the height is 70 centimeter, that is; the height of the tank and if we divide by the velocity you get 1571 seconds, that is; about 26 minutes, that means; it takes 26 minutes, for solid which at the top of the liquid level to reach the bottom of the tank of height 70 centimeter.

Now, this stoke law again if you remember recall that it is valid only when the Reynolds number is very very low that the Reynolds is less than 1.So, we need to confirm or check whether the Reynolds number is really low otherwise strokes law is not valid. Why is it so? If you remember Reynolds number is a function of many parameters right diameter of the particle, particle velocity and the physic chemical, physical properties of the liquid. Now, the velocity is very high it may create a turbulence then the stokes law is not valid. So, we again have the particle size, particle velocity here we know the liquid density, liquid viscosity.

So, we introduce all the terms and we find that the Reynolds number is very small much less than 1. So, it is for to use this particular equation otherwise it is not correct. So, stokes law depends upon dilute solutions, that means; solids that are settling down is not disturbing or impeding the solids that are present so, that may 1 solid may affect the movement of other solid either through collusion or creating eddies or creating turbulence.

Then we cannot use the assumptions of stoke law that mean if the concentration is very high we cannot use the stoke law. If the velocities are very very high in the form of turbulence then again the stoke law is not very valid. What happens when the particles are not very spherical? We can still use stoke law we will use something called the characteristic diameter of the particle. How do you calculate characteristic diameter of the particle? All we can do is get the volume of the particle divided by the surface area of the particle. So, when you do that from there we can calculate the characteristic diameter of the particle.

Now, what is the through put in the settling tank? How do you calculate through put? Through put is the tank volume divided by the back cycle time. So, is the back cycle time we will assume it as the settling time 26 minutes and the tank volume is nothing but this is the diameter of the tank so, it gets pie d square by 4, this is; the height of the tank so, you multiply that gives you the volume divided by 26. So, through put through the tank is about 210 cubic centimeters per minute.

So, you can process 210 cubic centimeters per minute of this particular slurry and achieve a separation between solids and the liquid through settling. And, approximately it will take 26 minute for the solids to settle but in reality the solids may take slightly more time to reach the terminal settling velocity. So, you may have to keep the slurry inside the cylindrical tank for much longer than 26 minute to achieve a real complete separation.

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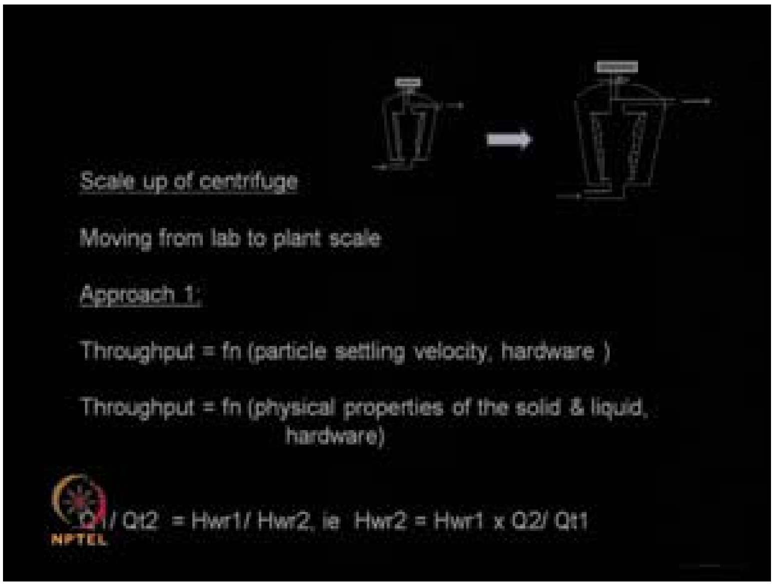

Let us look at something called scale up. Scale up is very very important part bio process technology or even downstream processing technology. Because whatever we do in our lab the main intention is to emulate or practice in large scale. Large scale could be your pilot plant or your semi technical plant or full manufacturing plant. So, in a lab I may be using 100 cubic centimeter or 500 cubic centimeter or 1 liter.

But in full manufacturing plant I may be doing operation in 10,000 liters or 20,000 liters or even 100,000 liters. So, whatever I practice in the lab should be happening in the large scale as well actually. So, when we move from lab to plant the question always arises what should be my operating conditions? What should be the size of the large scale vessels?

So, if I have a centrifuge of certain dimensions what should be the dimensions of the centrifuge of the large scale? Or if I consider a large centrifuge how much difference will be it is performance if I compare it in my small scale? So, these questions are always asked by the process engineers or bio chemical engineers or a scale up chemist. So, there are 2 different approaches by which scale up centrifuges.

Let look at approach one I introduced some equations relating to centrifuge long time back where I said the through put, that means; the quantity of slurry that is flowing through liters per minute or meter cube per hour. Whatever it is quantity of liquid that is flowing through is a function of the particle settling velocity and the hardware parameters.

That means, it is a multiplication of a terminal settling velocity and hardware. Hardware means the revolutions per minute the height of the centrifuge diameter of the centrifuge and if you had Disc centrifuge the number of discs those are the hardware details. Particle settling velocity involves the physical properties of the solids and the liquid like the diameter of the solid, viscosity of the fluid, density of the fluid, density of the solid and so on actually.

So, if I have certain data on small scale I can extend it to a similar designed hardware, that means; geometrically similar designed hardware using this particular relationship that means through put is of function of particle settling velocity into hardware. So, through put in centrifuge 1 divided by through put in centrifuge 2 is same will be equal to the hardware centrifuge 1 divided by the hardware details of centrifuge 2, assuming that the hardware particle settling velocity does not change when you move from one scale to another. So, if you have assumed that the particle settling velocity does not change then through put is directly proportional to hardware.

So, I can say q1 by, that is; q 1 is a through put in centrifuge 1 divided by the through put in centrifuge 2 equal to hardware 1 divided by hardware 2 or I can do some mathematical manipulation and can say that the hardware 2 will be equal to hardware 1 multiplied by q 2 by q 1. So, q 2 by q 1 tells you how much scale up I m going to perform with respect to through put. So, you multiply the hardware 1 value with the particular ratio of q 2 by q 1.

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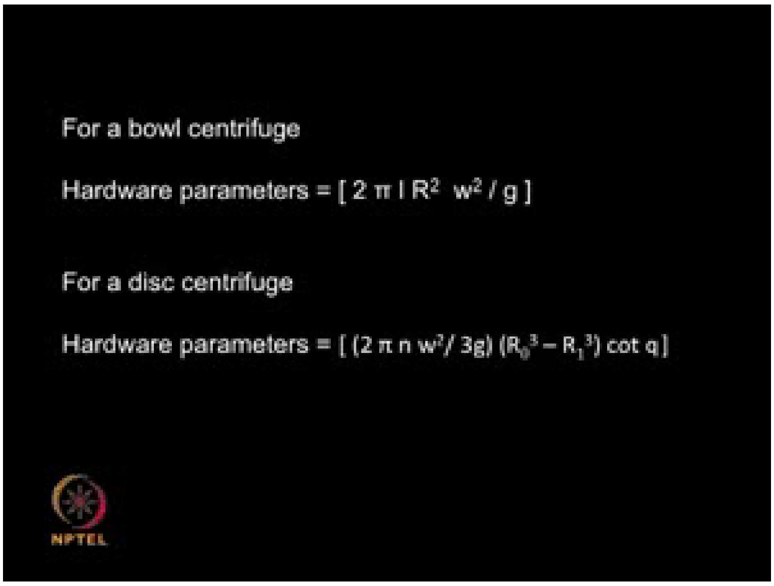

Let us look at the problem. Now, Let us recall these hardware parameters for bowl centrifuge and disc centrifuge I have shown this particular set of equations in the previous class. So, for a bowl centrifuge they have a parameter is like this were the L is the height of the centrifuge or length of the centrifuge R is your radius of the bowl. This is your revolutions per minute were as in the disc centrifuge the equations become slightly more complicated because you have several incline discs.

So, n is the number of discs and then you have terms like radius of the disc. And, then angle the discs make with respect to the central a cubic centimeters. But basically, if you see this term relate to the hardware of the centrifuge, disc centrifuge this term relates to hardware of the bowl centrifuge.

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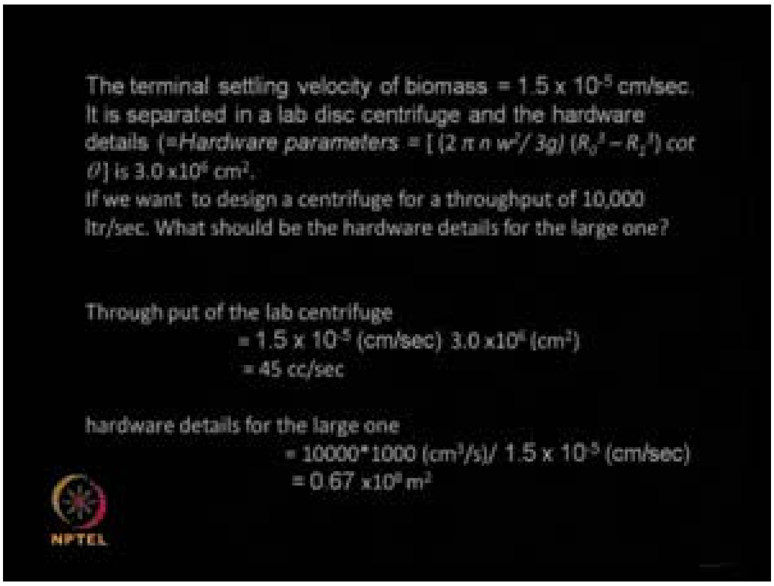

Now, the terminal settling velocity of a bio mass is given here, 1.5 into 10 power minus 5 centimeter per second. It is separated in the lab using a disc centrifuge and the hardware detail parameters means, hardware parameter is 2 pie n omega square 3 g. You have r naught cubes minus r 1 cube cot theta. Now, this is equal to 3.0 into 10 power 6 centimeter square. So, you have used lab scale disc centrifuge and you have separated some solids whose terminal settling velocity is given. Now, I want to design a very large scale set up to achieve a through put of 10,000 liters per second. What should be the hardware details for the large one?

Now, the hardware details for the large centrifuge is given and the through put of the large scale is also given that is 10,000 liters per second which can be converted in to so many cubic centimeter per second. The terminal settling velocity is also given 1.5 into 10 power minus 5 centimeter per second. So, the through put divided by the terminal settling velocity will give you the hardware details for the large centrifuge. So, you see this is the hardware details for the small centrifuge; this is the hardware details for the large centrifuge.

Now, this small centrifuge what the through put? You just have to multiply the terminal settling velocity and the hardware, that means; 1.5 into 10 power minus 5 multiplied by 3.0 into10 power 6. So, you get 45 cubic centimeters per second. So, you are scaling up from a 45 cubic centimeter per second to 10,000 liters per second, that is; the scale up you are using the same structure disc centrifuge.

In the small scale the hardware detail the hardware parameter is 3.0 into 10 power minus 6 centimeter square in the large scale hardware parameter 0.67 in to 10 power 8 meter square. But the terminal settling velocity is the same whether it is a small scale or whether it is the large scale. Because the main assumption here is the particle and the fluid properties do not change.

Now, how do you achieve this particular number for hardware parameter? It can be achieved through so many terms here; it can be achieved through increasing the number of discs it can be achieved through changing your inclination, that is; theta with respect to central access it can be achieved through changing the r naught understand. So, that is lift to you can go to a vender and look at all the centrifuges available with him and then you can see which centrifuge has a hardware parameter closer to this understand.

So, you may different combination of radius, you may have different number of discs. So, you can select one of them depending upon which one is closer to this 0.67 into 10 power 8 meter square. So, this is a very simple approach by which we can scale up centrifuges moving from the lab to full scale commercial plant. So, your main assumption here is the q that is the through put is equal to the terminal settling velocity multiplied by the hardware parameter.

Terminal settling velocity does not change when you scale up to small scale to large scale because it is a function of particle properties and the fluid properties. The hardware parameters include the revolutions per minute the radius of the centrifuge. And, if it is a discs centrifuge you will also have terms like number of discs and also the inclination the disc make with the central axis. So, those are terms which also appear and compare to the bowl centrifuge and the discs centrifuge.

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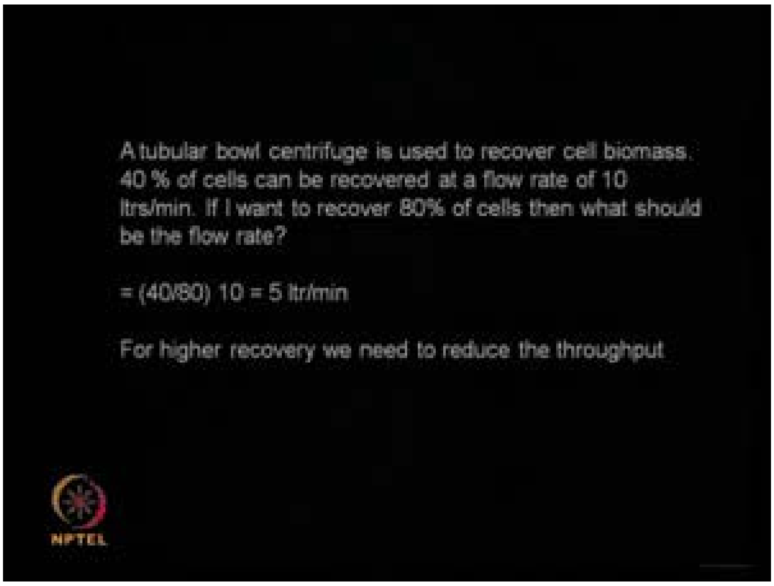

So, we are using a tubular bowl centrifuge to recover cell bio mass. So, if I use 10 liters per minute I am able to recover 40 percent of the cells. But then I need to recover 80 percent of the cells. So, what should be the through put? Or the flow rates do? It will be directly proportional to the percentage recovery that means; you want to have 80 percent of cells recovery that means; you would like to improve the efficiency. So, obviously you have 40 divided by 80 and 10 is the original flow rate. So, the flow rate has to be reduced by factor of 2. So, if you want to improve the efficiency obviously through put goes down for higher is the efficiency through put has to go down.

But if I want to have higher efficiency and also higher through put then obviously, I need to change the hardware parameter, maybe I will change the revolutions per minute or maybe I will change the diameter of the centrifuge and so on. So, those are related to hardware, but if I have the same hardware. And, tomorrow you are asked by your boss to add the efficiency of recovery then the only way you can do is to decrease your through put that is; there is no other way at all.

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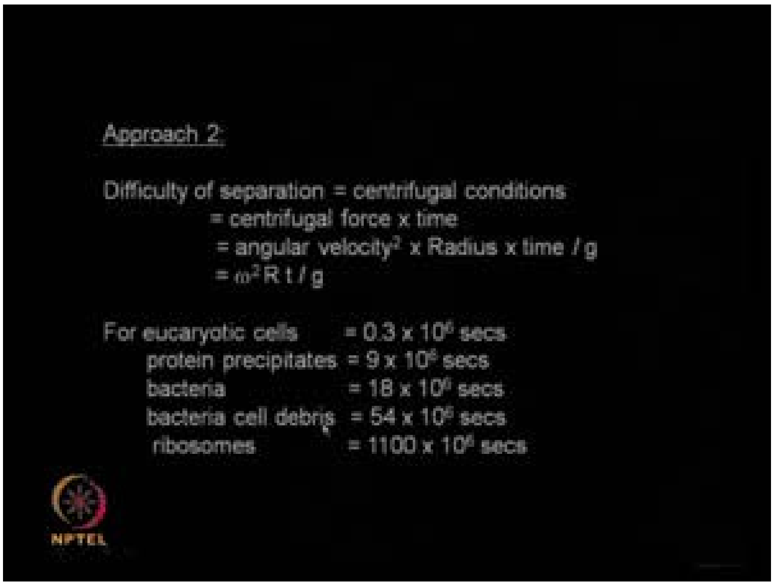

Now, one approach we talked about which gives you an idea of how to scale up centrifugal operation when you move from the lab to a full scale commercial plant. The equation is very simple it says through is equal to terminal settling velocity into hardware diameters. So, that means through put is directly proportional to hardware parameter that means; through put in centrifuge 1 divided by through put in centrifuge 2 will be equal to hardware parameters in centrifuge 1divided by hardware parameters in centrifuge 2. So, if I know the details in small scale I can estimate the details for a large scale.

Now, there is another approach by which we could do scale up that is called difficulty of separation or the centrifugal conditions. So, difficulty of separation is calculated by looking at the centrifugal force multiplied by time. Centrifugal force is calculated using the angular of velocity the radius of the centrifuge and a time and off course g comes there. So, difficulty of separation is given by omega square R t by g this is called the difficulty of separation.

So, when you move from small scale to large scale you can keep this omega square R t by g as a constant. For example, for necrotic cells this particular term is given like this. For proteins it is given as 9 into 10 power 6,for bacteria 18 into 10 power 6, bacteria cell debris its 54 into 10 power 6, ribosome 1100 into 10 power 6. So, why it means; is it is very very difficult to separate ribosome when compared to bacteria cell debris, bacteria, protein precipitates or eukaryotic cells.

So, obviously it means it is more difficult to separate cell debris then cells itself. And, we can scale it up based on the difficulty of the separation that means; when I move from a small scale which has certain value of omega R and t. And, when I move to larger scale and I want to separate bacteria cell debris. Then I can keep the same number 54 into10 power 6. But it may have different omega, different radius, different time but the product of omega square R t by g will be the same irrespective of the scale. Whether I do it in a small scale or whether I perform the operation on the large scale I maintain omega square R t by g constant for the particular systems understand.

So, in a large scale I will give omega square R t by g as 54 into 10 power 6 if I am removing cell debris or if I am doing the same removal of cell debris in my lab I still keep R t by 10 power 654 into 10 power 6 seconds. So, from this particular solutions moving the R, that means; the radius of the centrifuge and knowing the revolutions per minute I will be able to calculate the time understand or If I know the radius of the centrifuge I if I know the time of the centrifugal operation I can calculate what will be the omega. Because I will assume the difficulty of separation to be constant and it only depends upon the type of material does not depend upon the hardware details understand.

Type of material means that it could be the bacterial or it could be eukaryotic cells or it could be protein or it could be cell debris or it could be ribosomes. So, I can estimate this particular term omega square R t by g in my lab, that means; I take a small centrifuge I know the radius of the centrifuge, I know at what revolutions per minute it is rotating.

And, then I separate the solids from the liquid I find out how long it takes to do that operation and then I multiply omega square R t by g and I will take this term as a constant, whether I doing it in the lab or whether do it in the full scale production. So, this is the second approach by which we can scale up a centrifuge and that is based on the difficulty of separation.

So, the first approach through put is equal to the terminal settling velocity into hardware parameters. Second approach is based on constancy of the difficulty of the separation. So, the difficulty of separation remains constant whether it is in the lab or in the full scale plant. And, this term is given by omega square R t divided by g. And, we can estimate it in your lab centrifuge and you find out how long it takes to remove the solids from the liquid? Or separate the solids from the liquid using a small centrifuge of radius R which is rotating at a angular of velocity omega.

Thank you.