Downstream Processing
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Lecture - 9
Solid Liquid Separation – problems

We have been talking about solid liquid separation, and we will continue with the same topic today as well.

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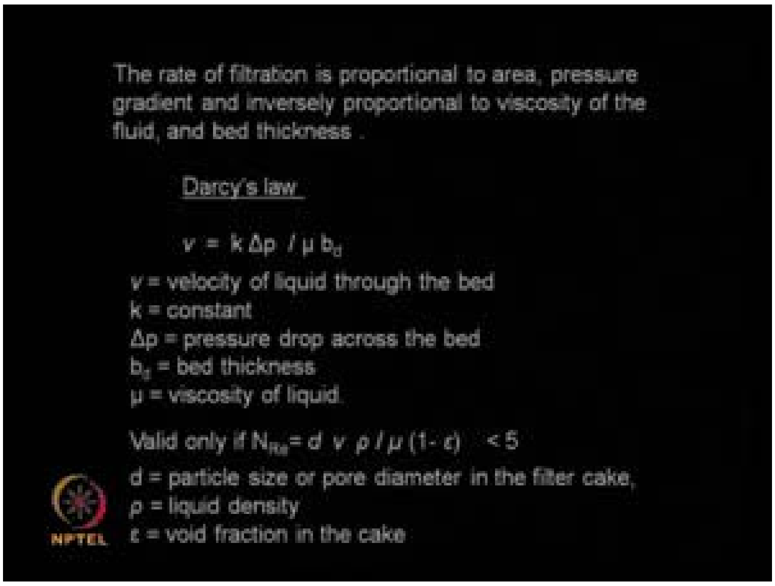

The most important equation is the Darcy's law. And the Darcy's law relates the throughput that needs to be filtered or the velocity of the liquid flow as a function of the pressure drop, the surface area for the filtration as well as the bed thickness. So, the viscosity of the fluid and the bed thickness are contributing in a inverse fashion towards the rate of the filtration; whereas the pressure drop and area or the filtery contributes in direct manner towards the rate of the filtration.

So, in the last class we saw that the Darcy's law appears like this, velocity is equal to K that is a constant, delta p that is the pressure drop, mu is your viscosity of the medium, and b is your bed thickness. So, it is very simple equation and it assumes certain conditions especially relating to the Reynolds number.

So, the Reynolds number has to be within certain region; then only this law is applicable otherwise you have very concentrated slurry. And it might not be applicable at all to the velocity the Reynolds number has to be less than 5. And the Reynolds number as you know is defined in this particular fashion that is the diameter of the particle d, the velocity of the fluid flowing, row is the density of the fluid, mu is the viscosity of the fluid. And in addition we also have a term called 1 minus epsilon; epsilon is the porosity of the bed.

So, this is how the Reynolds number is calculated and the Reynolds number should be less than 5 for the Darcy's law to be valid. But then although the Reynolds number is needs to be less than 5, we still use this equation as the first approximation to calculate the throughput of the filtration process. So, we can use this model for doing lot of calculation; we can use it to calculate what should be the time to filter slurry of the certain volume or conversely if we decide on the time we can calculate the area required for performing this particular filtration process? And that is what we will try to derive that is the equation which we will try to derive actually.

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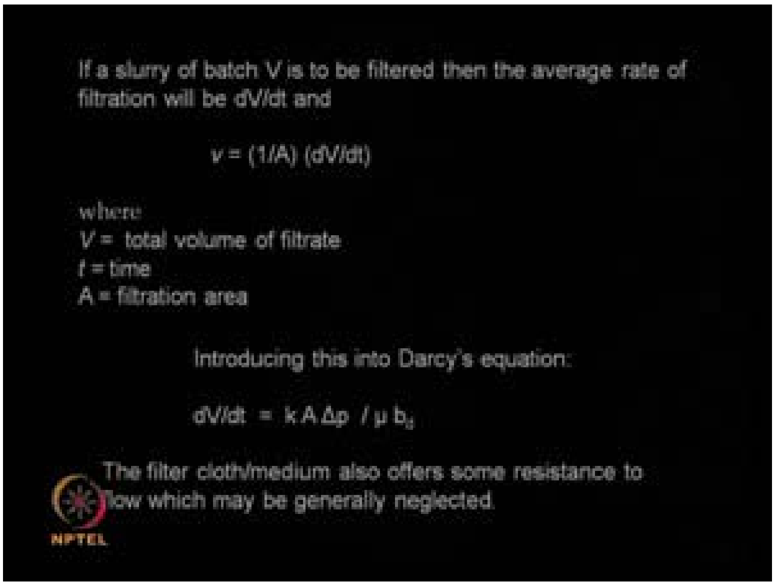

So, if we looking at velocity of flow through a bed and the volume of the liquid that is needs to be filtered. Then the velocity in the volume will definitely be related to this; that is velocity is equal to d v by d t; where v is the volume and t is your time. So, d v by d t is the average rate of filtration and the whole thing is divided by area; A is the filtration area. So, if the filtration area is very, very large then the velocity will be very less. So, we can use this equation to do lot of things.

So, we can introduce this equation to Darcy’s law. And then we will end of the differential equation for average volume of filtration for a given time as a function of delta p that is the pressure drop, A is your area and b is your bed thickness and mu is your viscosity of the medium.

Now, there are several assumptions which we need to make before we actually solve this particular equation to arrive at something meaningful. The first assumption is we will assume the filter cloth or filter medium does not offer any resistance. So, if we can assume if you assume that then it is very simple for us to integrate these equation. And array at relationship for time as a function of all these parameter.

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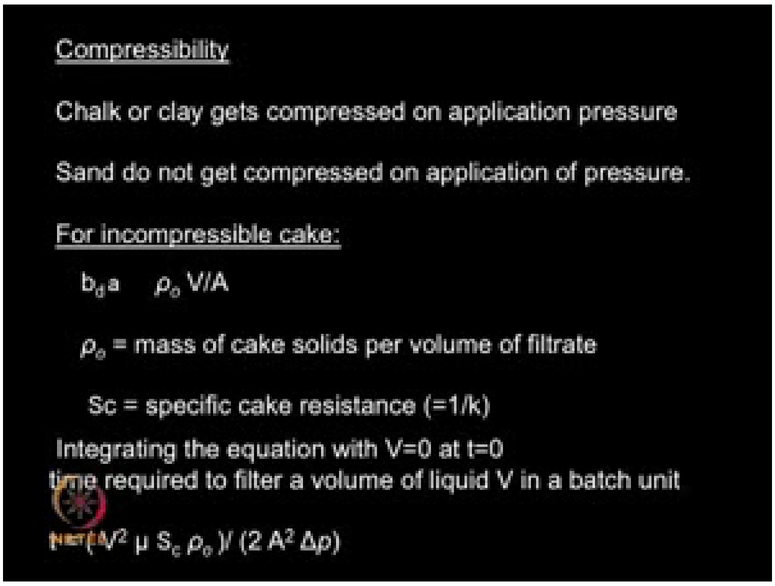

So, we will assume that the filter cloth does not offer any resistance number 1. Number 2 sometime the bed itself can offer resistance if increase the pressure of filtration process. So, if the bed pressure increases as we keep on applying an external pressure then it is called a compressible solid. That means, as we keep increasing the pressure the bed gets more compacted. So, that is called the compressible solid; especially solids like a clay, chalk make it compress when you apply lot of pressure.

So, in so they are not very good if you want to apply high pressure whereas, on the contrary if you take sand even if we apply in very high pressure sand will not get compressed; because they are very porous. So, in such situations by increasing the pressure we will be able to increase the rate of filtration. So, for uncompressible solids the rate of filtration can be increased by increasing pressure whereas, if it is a compressible solid like a clay or chalk by increasing the pressure you are in the trouble; you will be reducing the flow because the material gets compacted.

So, when you assume the solids are incompressible that means there is no change in the porosity; if I keep increasing the pressure across the bed. Then we can say the b d the bed thickness as a function is equal to row naught. Row naught is the term which is defined as a mass of cake of solids per volume of filtrate multiplied by V is the total volume divided by the area. And if you assume the specific cake resistance as the capital which is equal to capital Sigma c is equal to 1 by k; k is your constant which I defined in the Darcy's law.

Then, you will end up in integrating this Darcy's law by assuming at t equal to 0 the volume that filtered is 0; by doing that we can get a relationship for the time required to filter the volume of the liquid V in a batch unit. So, this time the function of many parameters the volume that needs to be volume of slurry that needs to be filtered, mu is viscosity of the medium, row naught is the mass of cake of solids per volume of filtrate, A is the area of the filtration unit, delta p is the pressure we apply.

So, you see this equation is obtained by assuming many situations; one is we assume that the filter cloth or the filter medium does not offer any resistance number 1. Number 2 we assume that the solids are incompressible and then number 3 we assume an average rate of filtration. That means we assume d v by d t which is average rate of liquid that filtered over a period of time.

So, by assuming these 3 we end up with relationship for the time of filtration to filter slurry volume of V. And these are the physical properties of the slurry as well as the liquid that is mu is viscosity of the liquid, row naught is the mass of the cake solids per volume of filtrate as you keep filtering, A is the cross sectional area and delta p is the pressure.

So, with these equation we can do many things. So, if I know how much liquid or slurry that is need to be filtered. And if I know the area of the filter unit I can calculate how long it will take to filter or conversely if I want to filter a slurry of volume V in certain given time t; what should be my area of the filter per unit I can calculate from this equation.

So, I can do both; I can use it as design equation or I can use it as the simulation equation and these a very interesting equation. Because by assuming several condition we got very simple equation and it is very useful to do make use of these equation for calculating the time of filtration or area required for the entire filtration process.

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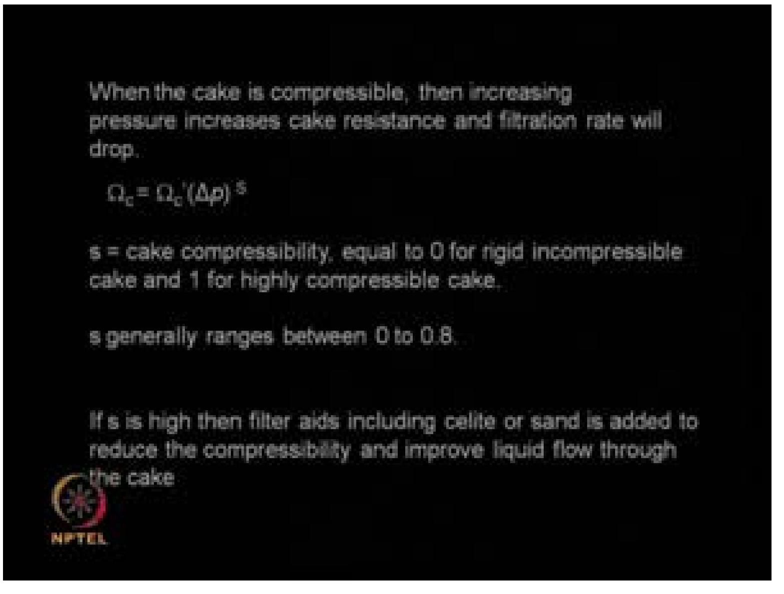

Now, if the cake is compressible previously you assume that the cake is incompressible. But if you assume the cake is compressible then as we increased the pressure the resistance also increases; because the material gets compacted. So, we write an equation for the constant like this; where s is a exponent which may vary.

And generally it is about 0 to 0.8; if it is highly compressible we will take as s almost equal to 1 which not at all compressible that is if it is incompressible s will be 0. So, you see that this particular equation mentioned that the resistance offered by the cake towards the flow of the liquid is directly proportional to delta p rise to some power some exponent.

And, generally we can take these exponent around 0.6 or 0.7 or 0.8 and so on. So, in such situation what you will do? If you want to filter a material which is going to get really compacted as increase the pressure we are something called filtrate. Filtrate is like acelite; sand all these what does it? It reduce the resistance offered by the cake that means it converts a compressible solid into partially compressible or incompressible. So, that the liquid can flow through. So, if you have that type of situation then you have a term called delta p rise to the power s.

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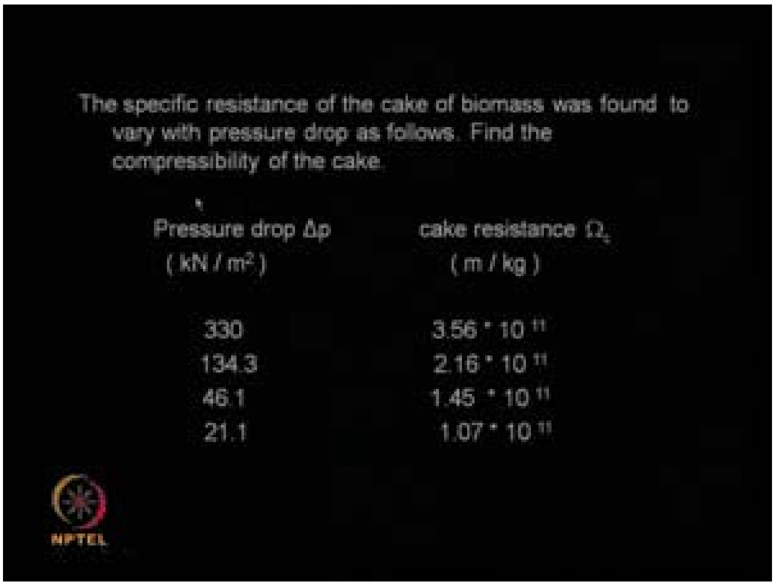

Let us look at a simple problem that will give as an understanding of this concept of incompressible solid as well as the compressible solid. So, if you want to know whether you are cake is compressible or not; what you do? We perform the experiment at different pressure and then see what is the resistance offered by the cake; that means cake resistance. So, from that we can find out whether the solid which you are going to filter is compressible or is not compressible.

So, imagine I have done some experiment and at the different pressure delta p; you get different cake resistance. So, what you do? You can plot the logarithm of this delta p and the logarithm of cake resistance. And see how the line looks like whether it passes through the origin or whether it does not pass through the origin.

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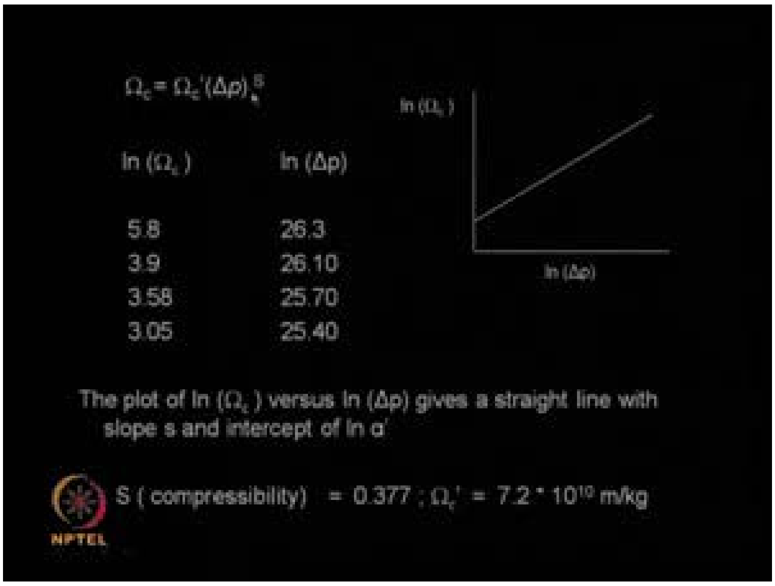

So, this is the relationship if you recall. So, if you take logarithm of the left hand side as well as the logarithm of right hand side what happens? You will have s as the slope of the double log plot and this term will become the intercept; logarithm of that will be intercept. So, in that problem I take logarithm and I take logarithm of delta p; and then in the x axis I plot the logarithm of delta p, in other axis I plot the logarithm of the sigma.

So, what happen? It does not pass through the origin. So, what does it mean? The material is compressible. So, if it is passes through the origin that means s is equal to 0. That means, the resistance offered by the cake is independent of delta p whereas here it is not passing through the origin right.

So, the plot of logarithm of these term versus the plot of logarithm is a straight line which slope s and intercept is equal to this particular term actually. So, the compressibility is from this we can calculate compressibility is 0.377. So, if you are doing filtration experiment. And you want to know whether the material is compressible or not you; what all you have to do is perform the experiment at different pressures.

And then calculate the resistance or resistivity and then plot a graph between the logarithm of delta p versus the logarithm of this particular term. And then see whether the line which you get passes through the origin or not. And then the slope of that line will give you this term which is called the relationship between the effect of the delta p on the resistance offered by the cake.

So, if this slope is equal to 0 that means or it can be equal to 1, it can be either 0 or it can be 1. So, it can take up both these value; and most of the material will lie always lie between 0 to 1. So, if it is 0 that means the it is independent delta p that means there is no effect of pressure on the resistance offered by the cake whereas if it is 1. That means, it is maximum effect of pressure on the resistance offered by the cake.

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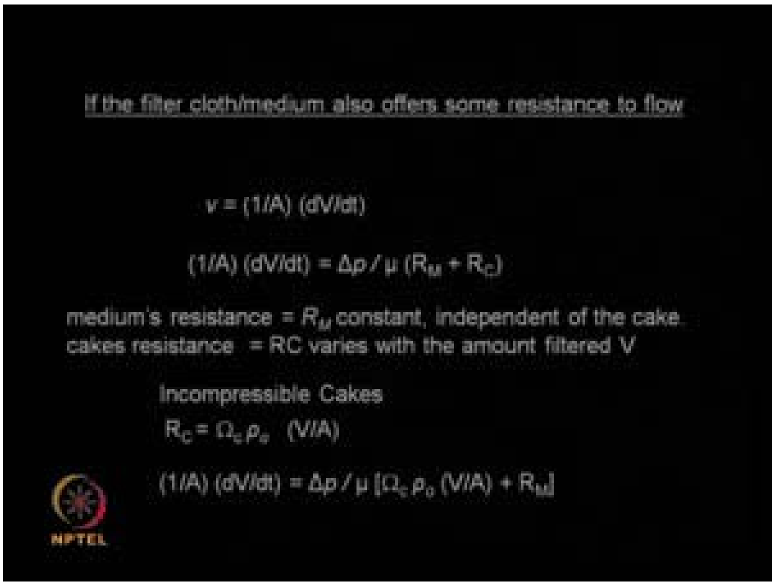

So, far we talk about the filter cloth or filter medium not offering any resistance to the flow. But there could be some situation where the filter medium itself can be offering some resistance to the flow of the liquid. Generally, if you design filtration unit you like to keep the resistance offered by the filter medium minimum. But there are situations where filter medium itself can offered some resistance.

So, in such a situation what you have the Darcy’s law equation is going to be different and the resistance offered by the cake also will appear in with the resistance offered by the filter cloth or the filter medium; both the resistances are going to appear in your Darcy’s law relationship. So, let us look it at again so as you know V equal to 1 by a and d v by d t; where a is the cross sectional area or the area of the filter setup, V is your volume of a slurry that needs to be filtered. And t is your time and the v is your v is your velocity.

So, if you are going to have 2 resistances; one because of the cake that is the R c and one because of the filter cloth or the filter medium. Then you are going to have both term coming into the picture. So, we are going to have 1 by A d v by d t delta p divided by mu R m plus R c if it take incompressible cake. So, this term will not have the delta p rise to the power s like we saw before.

So, by introducing all these into your velocity equation you are going to have 1 by A d v by d t equal to delta p divided by mu sigma c row naught v by A this term comes because of the resistance offered by the cake. And this term comes because of the resistance offered by the medium otherwise when there is resistance offered by the medium is 0 or the resistance offered by the filter cloth is 0; this term will disappear. This is your original equation which I showed 3 or 4slides before. So, what you do? You can now integrate these equation and get slightly different relationship between time volumetric flow rate and resistance offered by the medium.

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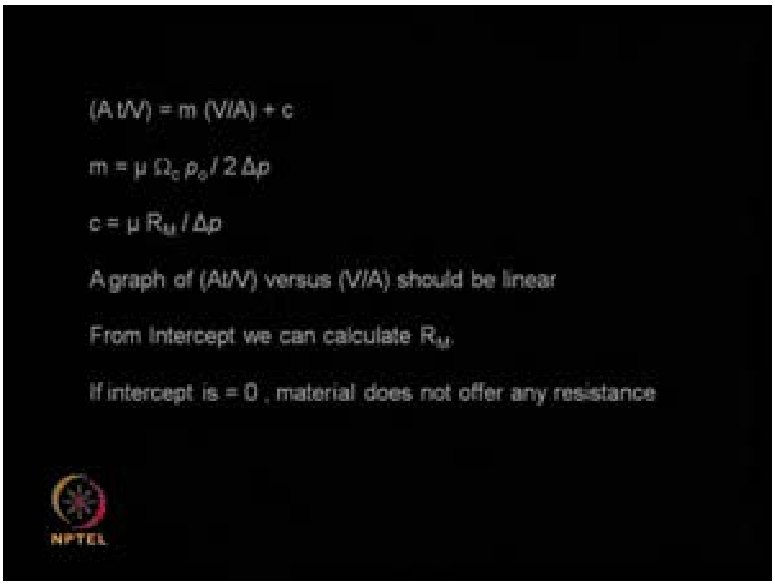

So, by doing that we will end up a relationship like this; A that is the area, t is the total time required to filter, a slurry of volume v multiplied by m V by A plus c; m is given like this and c is given by like this. So, here you have a term which is called R m that is the resistance offered by the medium or the filter cloth. So, if that resistance is 0 the term c will completely disappear understand.

So, you are you will have only the this relationship. This is relationship which I showed few slides back because we assume that the medium also offer some resistance; we have that extra term which come as a plus here. So, interesting if you look at these relationship if I plot A t by V as against V by A; you will get a linear relationship. And then from the intercept of that linear relationship we can calculate the R m term. Because this is like your original equation for a straight line y equal to m x plus c; c is your intercept, m is your slope.

So, from the intercept we can calculate the R m term here. So, the intercept is 0 that means this term is totally gone. That means, your R m that means the resistance offered by the medium or the cloth is the 0. But if you have an intercept that means the resistance offered by the cloth is not equal to 0. So, I just plot A t by V as a function of V by A in a graph sheet.

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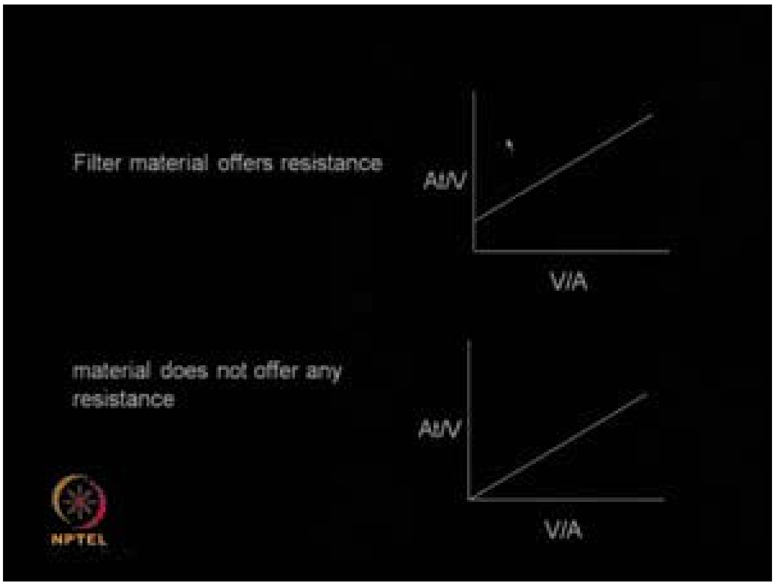

So, the material or the cloth offers some resistance I will get some intercepts with material does not offer any resistance; I will not get any intercept. So, I can I will immediately know whether my the cloth filter cloth I used is offering considerable resistance or not. So, here V is the amount of liquid that needs to be filter, t is the total time that it will takes to filter that and A is the cross sectional area of the filtration setup.

So, it is simple. So, I take different amount of slurry I filter them at a constant delta p; calculate how long it takes to filter the different amount of slurry? And then I will do all a plot a graph between A t by V versus by A. And then I see what type of straight line I get whether it passes through the origin or whether it does not pass through the origin.

If it is passes through the origin I will say the filter cloth offer does not resistance whereas it does not pass through the Origin I will know the filter cloth offer some resistance. So, you can find out whether it is considerable value or it is very insignificance. If it is considerable value as a design engineer you may have to select some other filter cloth or filter medium whose resistance is very very small. So, please keep that in mind.

So, if the intercept the intercept is large then you know the filter cloth or the filter medium is you used does offer some resistance. So, ideally it should be as close to the origin as possible. So, we saw different situations we took the Darcy's law. And then we said velocity of flow is equal to 1 by a d v V by d t V is nothing but the volume of liquid that is need to be filtered. So, d V by d t is average rate of filtration; on the left hand side you had a velocity and then we had the Darcy's law incorporated to that.

Then, we looked at different situation. Situation number 1 is whether the bed is compressible or incompressible. So, if the bed is compressible then the resistance offered by the cake will be directly proportional to delta p rise to the power some exponent term. That means, as the pressure increases the resistance offered by the cake also increases and that the exponent is 0. That means, it is incompressible solids like sand whereas delta p is equal to 1 it is highly compressible and it offers some resistance like clay and so on. So, as the resistance which is directly proportional to the delta p as keep increasing to delta p is resistance is also goes up.

So, initially we looked at a incompressible cake model and we derive a relationship for filtration time as a function of many parameters; volume that needs to be filtered, the cross sectional area of the filter setup, the viscosity of the medium and the resistivity factor; then we went to compressible situation. So, that the resistance term will changed altered slightly different and you will have a extra term to delta p rise to power s. Then we looked at the resistance the offered by the filter medium.

That means, resistance offered by the filter cloth or the filter plate or the filter candle. So, once you assume that your Darcy's law get slightly modified and you get an extra term; you get almost like a y equal to m x plus c. That means, a linear relationship c is intercept which arises because of the resistance offered by your filter medium or filter cloth. And when you plot A t by V as a function of V by A; if the resistance offered by the filter cloth is appreciable we get a intercept. And if the resistance offered by the filter cloth is practically 0 then the line will pass through the origin.

And, I also mentioned that if the intercept is also appreciable then you know the that filter cloth offers that at large resistance. So, you need to be modified that filter cloth. So, that the resistance is coming down to practically 0. If a cloth is going to offers some resistance you need to apply more pressure during the filtration process. More pressure means a larger pump. A larger pump means you are going to spend more money especially in the capital cost as well as in the operating cost.

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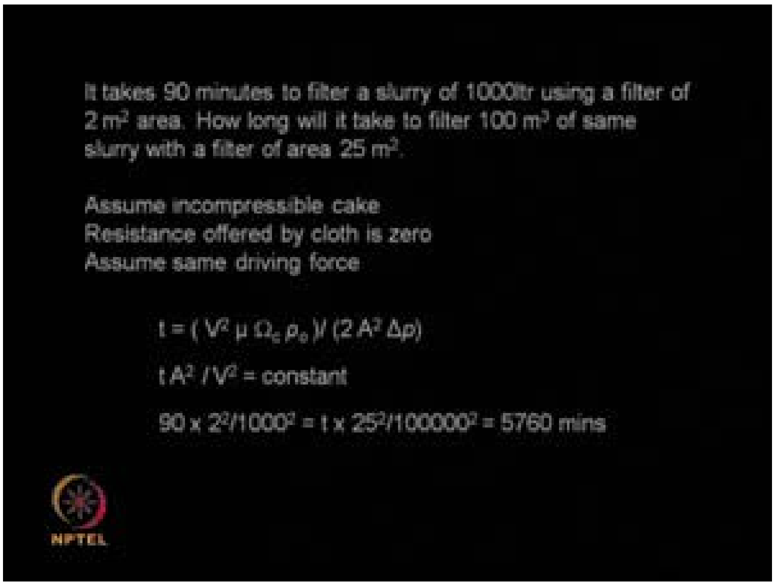

So, let us look at a simple problem which gives some idea about calculating filtration process and so on and so on. Now, it takes 90minutes to filter a slurry of 1000 litres using a filter setup of 2 meter square area. That means, area of the filtration setup is 2 meter square and the amount of slurry I need to filter is 1000 litres and it takes 90 minutes.

Now, I want to filter 100 meter cube of the slurry using a filter setup which has 25 meter square cross sectional area. So, we can assume incompressible cake we can assume resistance offered by the cloth is 0 assume same that means I am applying same delta p. So, you know this equation which we got this is simplest of the equation; where we assume the solid are incompressible, the filter medium does not offer any resistance.

So, this is the equation. So, we can bring the A here. So, we have t A square by V square is a constant correct; that means you are bringing A to the left hand side. So, it comes to numerator you are bringing the V to the left hand side; so it comes to the denominator. So, t A square by V square is constant.

So, initially it is given as 90 minutes to filter 1000 litres that comes in the denominator using a 2 meter square area filter setup. So, 90 into 2 square divided by 1000 square. Now, this is equal to t; t is what we have to calculate that is the time for filtering 100 meter cube. So, 100 meter cube is as you know 1 meter cube is 1000 litres. So, we have 100; 1000 in the denominator which is raised to by 2; in the surface area for filtration process is 25. So, you have 25 square; so you have to calculate t. So, you have to take these 2 terms together side you get 5760 minutes.

So, very simple problem but a it is got implication especially during scalar. When I am scaling up a from lab scale going to a pilot plant and going to a full scale, commercial amount that is needs to be filtered also keeps increasing. I might not be able to increase my filter area to much. So, what is the next alternate? I need to take much longer time to filter the liquid or the slurry.

So, that is what is happening here. In my pilot plant maybe I am filtering 1000 litres but in my large scale commercial plant I need to filter 100 meter cube of the liquid. Although, I am scaling up by surface area of filter setup from 2 meter square to 25 meter square this is not enough; because there are all related as a square. So, it takes 90 minutes to 5000 litre using 2 meter square whereas it takes 5760 minutes to filter 100 meter cube of slurry using a 25 meter square filtration setup. So, which means I will take several hours to filter 100 meter cube of liquid using 25 meter square filters setup.

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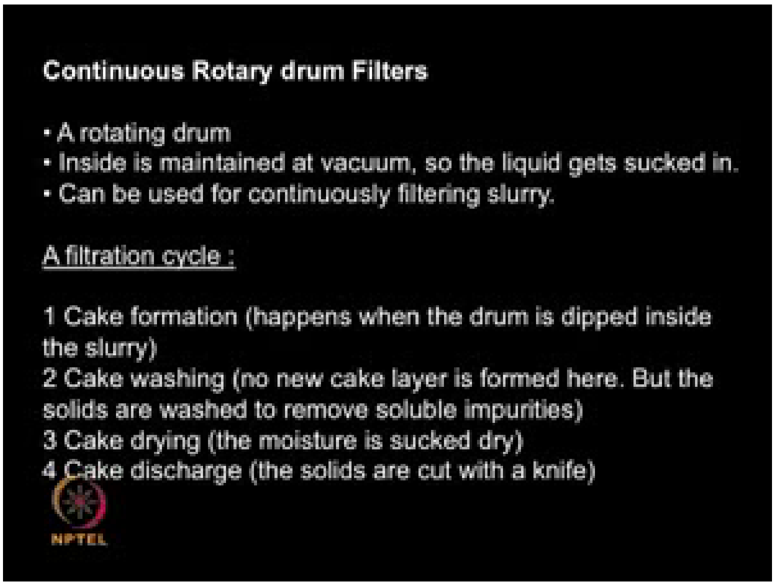

Now, we look at simple filtration setups. And we also look at some of the equations for filtering slurry when they are compressible bed or when the bed is incompressible or when the filter medium offers some resistance or filter medium does not offers some resistance. Now, even it look at the another type of filtration I showed you the picture of that before as well; it is a continuous rotary drum filters. You have a large drum rotating slowly and there is vacuum applied inside the drum.

So, the slurry gets sucked, the solids get retained on the surface of the drum, liquid travels right inside; as the drum rotates you may have washing of the cake that is deposited on the surface of the drum. So, if there are any impurities which dissolve in the washing of liquid they dissolve and get sucked in...

So, you have pure solids which is stuck on the top and that solid is crapped and collected. And then again the drum which is free from attack solid; once again a sucks in a the liquid and the solids in the slurry gets attach to the surface. So, this process keeps happening continuously. So, I can filter continuously a slurry, I can collect continuously wet solids; this quite not used in pharmaceutical type of applications where it happens continuously. And we continuously get wet solids which can go into a continuous drier and the solids can get dried and collected at the other end.

So, there are several steps during this process; the total filtration cycle is broken down into several steps. Step number 1 cake formation step; this is time when the drum dips inside the slurry. So, the drum is inside the slurry and there is vacuum applied inside the drum. So, the liquid a gets sucked inside the drum and the solids forms a cake or retain on the surface of the drum.

This is where the actual filtration takes place; once the drum comes out of the slurry there is no new cake that is been formed please remember that. Once the drum comes out of the slurry there is no new cake that is been formed but the solids are washed here. This is the cake washing cycle I may use water and use some solvent which will try to remove some impurities. So, if there are some impurities present in the cake that can be washed dissolved and removed; again the liquid gets sucked inside.

So, the washing of liquid is removed. The third step is cake drying; this is the time when the moisture that is still attached to the wet bed gets sucked. It does not get fully dried but some amount of moisture removal takes place. Finally, the solids are cut with the knife. So, this is where the cake gets discharged and the wets solids are collected for further processing.

And once the empty drum dips into the slurry tank and once again you form the cake and the processes goes on and on and on. So, here this is the cake formation step remember that where this is the time when the cake is formed the empty drum dips into the slurry tank; otherwise there is no cake formed. So, here we can use the same Darcy's law equation and go further on.

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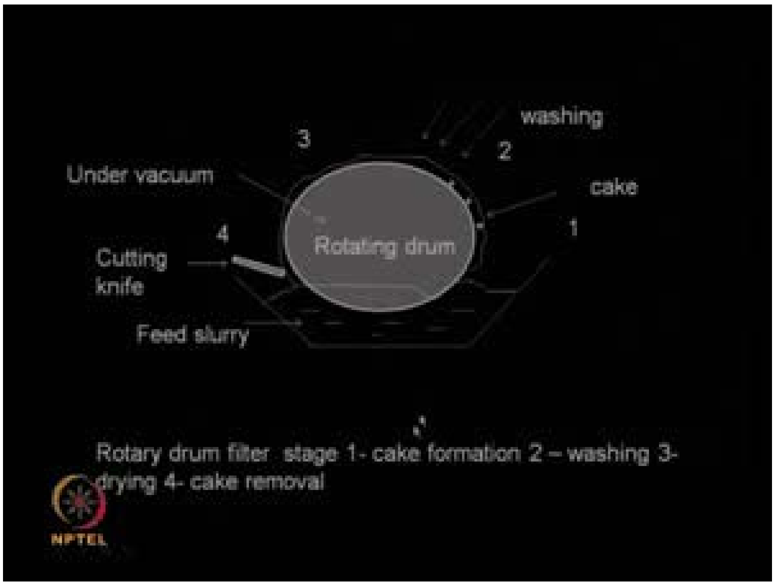

So, this is the setup; as we described in the previous slide. You have the cake formation when the drum is inside or dipped into the slurry; and you have a cake. Then here you are doing the washing using water or any solvent; once again the washing up liquid is sucked inside. This is the drying stage where the wet solid will slowly lose its wetness. Because the liquid that stuck to the solid gets sucked in. And finally here you have a cutting knife and the cake is crapped out and collected. And again the drum is empty and it dips inside the slurry tank. So, this process goes on and on.

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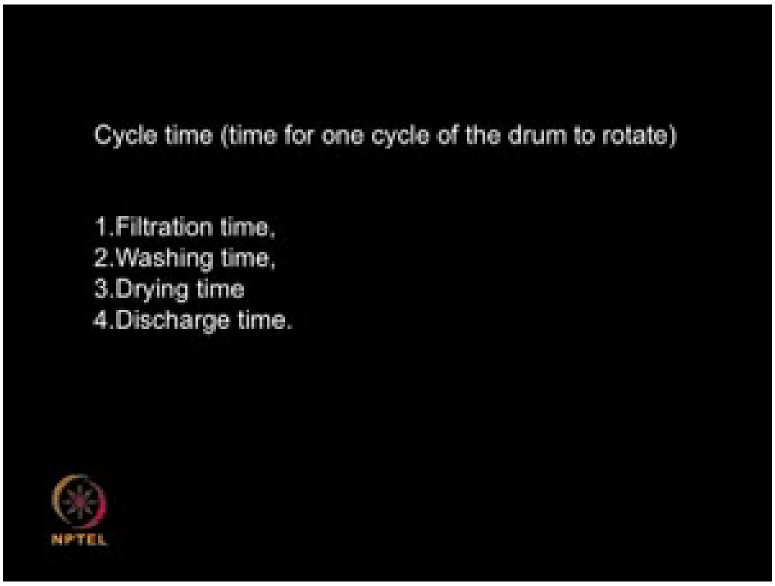

So, the cycle time that is time taken for the drum to start from the slurry tank go round. And finally reach the slurry tank is made up of 4 steps; one is called the filtration time, second is the washing time, drying time finally the discharge time; all these add up to get a cycle time.

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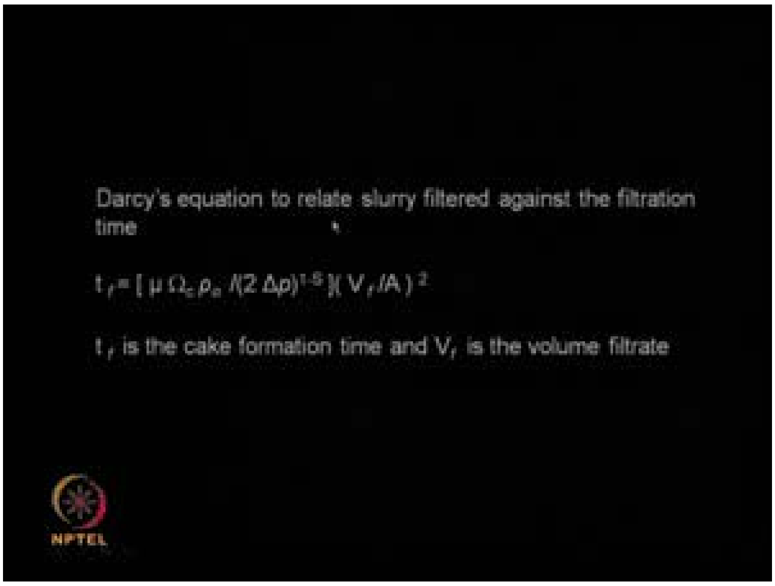

So, we can still use the Darcy's law during for the calculating the filtration time. So, if you remember from our old a previous slides you will get a relation for the cake time taken for the cake to form or to filter a slurry of volume V f; A is the area which is dipped inside your slurry tank, row naught as you know is the mass of the solid per volume, mu is the viscosity; and this the resistivity.

Here, we have assumed a compressible solids that is why you have delta p rise to power 1 minus s; do not forget that. Then if there is no compressibility then that term will disappear; the s term will become 0. Remember that there is cake formed only when the drum is dipped inside the slurry tank whereas when the drum is outside slurry tank there is no new cake that is been formed; the cake is getting washed. And the cake is getting dried, cake is getting cut.

So, during the first stage when the drum is inside the slurry tank we can use the Darcy's law relationship as we derived previously. And as you can see it is a function of amount of liquid or the slurry that is been filtered. It is a function of area inversely proportional to the area; it is a function of delta p. Because we have assumed compressible solid we got this term s. If the solid is not compressible we can just omit the s or s becomes 0. And these are the physical property of the liquid as well as the slurry density.

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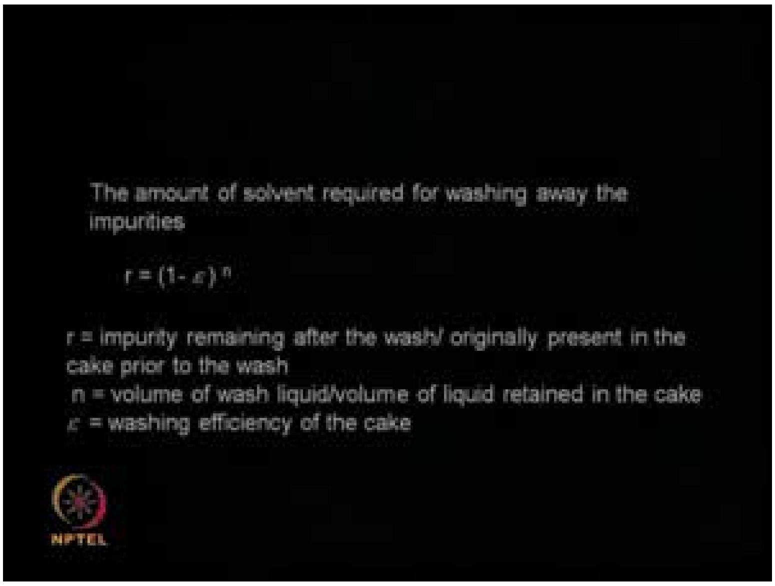

Now, you want calculate how much solvent or how much water is required to wash the cake? So, that we can purify the cake to high level or we can remove the amount of impurity present. So, you have an empirical relationship that relates the amount of wash liquid required. And the amount of washing efficiency and the amount of impurity that is present before washing and after washing. So, this is an imperical relationship based on lot of experience.

So, we cannot derive this particular relationship from fundamentals. So, this relationship as you can see says r is the impurity remaining after the wash divided by impurity that is originally present in the cake before the wash or this is equal to 1 minus epsilon rise to the power n; epsilon is the washing efficiency of the cake. Generally, we can take it as it is the function of the equipment.

So, generally you can take it as 70 prevent that means 0.7. Now, this is raised to the power of n; n is the volume of wash liquid divided by volume liquid retained in the cake. Because this is a solid will always retain some amount of the liquid; that depends upon the amount of wash liquid we used right. So, n is the function of volume of wash liquid divided into volume of liquid retained in the cake; all these are related to the impurity remaining after the wash.

So, if I know this term r; I can calculate n. Assuming epsilon to be around 70 percent; if I know n I can calculate r. So, this is an imperical relationship. So, it is not calculated based on fundamental principals but this is based more on experience. So, if I know n that means volume of wash liquid I am adding to the volume of liquid retain in the cake. Now, the volume of liquid retain in the cake is the function of the phyisco chemical properties of the liquid and the solid cake; volume of wash liquid is a function of solubility of the impurity.

Now, this is related to r on the left hand side; r is the impurity remaining after the wash and impurity that is present originally. Now, this the function of so many factor; this is the function of the solubility of the impurity in the washing up liquid, it is the function of efficiency of your equipment, it is a function of how much of a liquid retained by the cake. So, it is a very simple relationship r equal to 1 minus epsilon raise to n and it is a imperical relationship as I said. So, using this relationship we can calculate neither a knowing a right hand side we can calculate left hand side or knowing the left hand side we can calculate right hand side.

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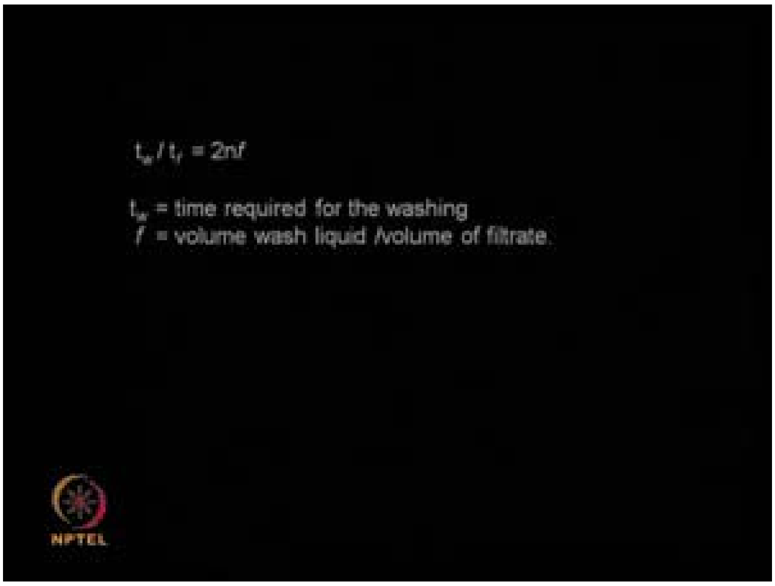

Now, there is another relationship it is again an imperical relationship t w divided by t f; t w is the time required for the washing, t f is the time for filtration that is the time when the a drum is inside the slurry tank, t w is the time for washing. So, tw/tf is equal to 2nf; as you know n is given here; n is wash liquid divided by the volume of liquid retained by the cake, f is the volume of wash liquid divided by volume of filtrate; again this is an imperical relationship.

So, if know the right hand side I can calculate the a left hand side t w or if I know t w, if know n; I can calculate f. So, you see this 2 equations; one is r equals to 1 minus epsilon raise to the power n and t w by t f is equal to 2 n f both are imperical relationship. And they relate several properties of the cake the impurity present, the solubility of the impurity in the washing liquid, the efficiency of your rotating drum filter, the amount of liquid retained by the solid cake and so on.

So, this are all related to the physico chemical properties of the impurity; the physical properties of your cake as against the physical properties of the washing of liquid you are using in. So, using these 2 relationship we can calculate many terms required for your design. How much of washing of liquid that I require to remove the impurity present in my cake from certain value say from 10 percent to 1 percent? How much of washing up liquid I require?

So, I can use these equations to calculate that or I can say if I have 10 percent impurity and I add so many 1000 litres of washing of liquid. How much will be the reduction in the impurity from the 10 percent to what value? So, I can use this 2 relationship they are very very simple relationship to calculate the impurity profile depending upon the amount of washing of liquid I am using. And depending upon the physico chemical properties of the impurity as well as the cake.

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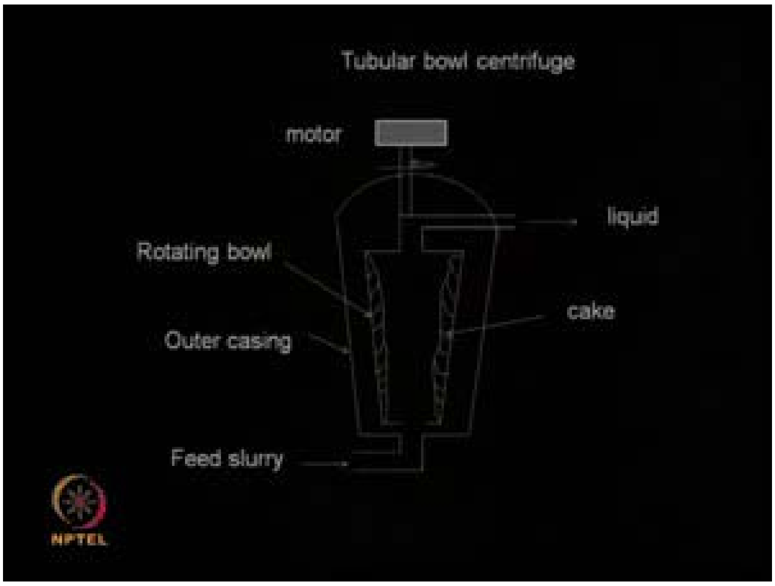

We will look at some problems in the next class. Now, the next design which we saw in the previous is a centrifuge; centrifuge achieves its driving force through the application of a high rotational speed. And because of this centrifugal forces solids get thrown out to this wall and the liquid flows right through the centre. And that is how you achieve a solid liquid separation.

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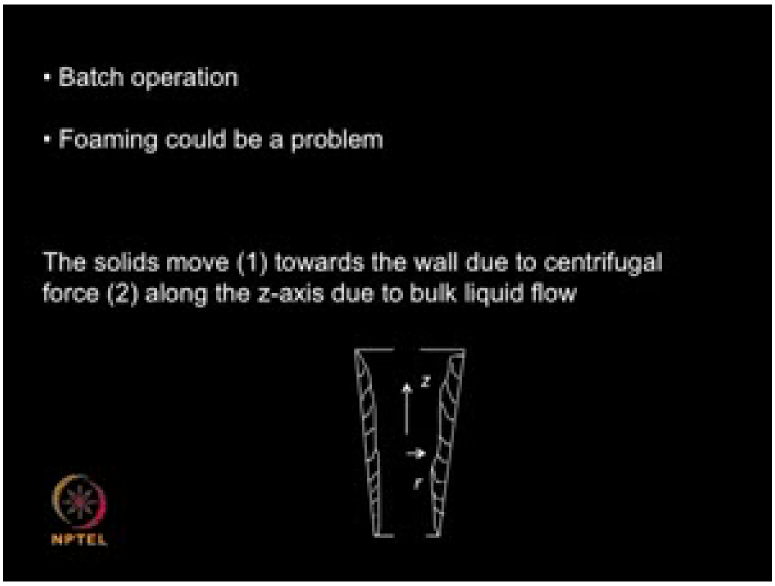

So, if you look at a tubular bowls centrifuge; they generally they operated batch conditions the foaming could be a big problem in this. So, if we take a solid which is entering the centrifuge 2 things are happening to the solid; one is because of the movement of the liquid the solids travel along the axis of the centrifuge number 1. Number 2 because of the centrifugal forces they are thrown at the wall of the centrifuge. And this is the function of the radius that is location radial location of the solid.

So, 2 things are happening; one is solids encounter a force along the axis. Because of the bulk flow and the solids encounter a force which is a centrifugal force. Because of the rotation of the centrifuge which is the function of the radial location of the particle.

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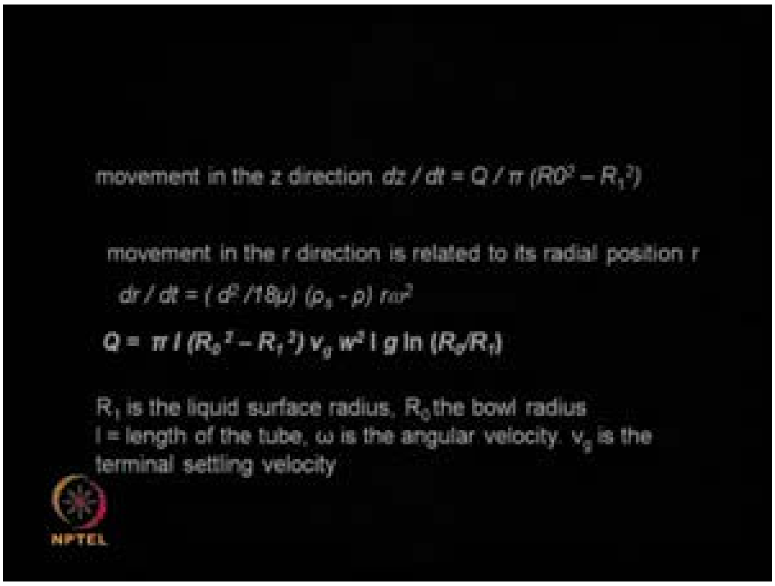

So, if you consider these the movement of the in the z direction that is along the axis. And the movement in the r direction that is the function of the radial position. We have 2 equations dz by dt and we have another relationship dr by dt. So, we can combine all these relationship to arrive at a final equation Q that is the throughput through the centrifuge a tubular bowl centrifuge as a function of R naught which is the bowl radius; R 1 this is the liquid surface radius, l is the length of the tube, omega is the angular velocity and v is the terminal settling velocity.

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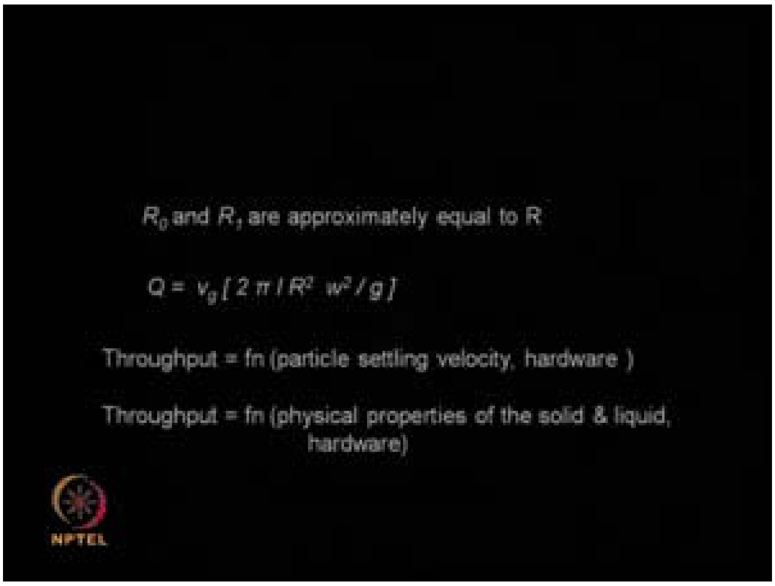

Now, if we assume R naught and R 1 that is the radius of the bowl and the radius of the liquid are almost equal and they are equal to R. Then the equation gets very simple simplified to this form Q equal to Vg that is the terminal settling velocity of the solid, l is the length of the centrifuge, r is the radius of the centrifuge we can take it as, omega is the angular velocity divided by g. So, what is this mean throughput is the function of the settling velocity. And these are related to the hardware of the centrifuge as well as the operating angular velocity.

Now, as you know that settling velocity is the function of the physical properties of the solid and the liquid like the diameter of the solid, density of the liquid, density of the viscosity of the liquid. Because I talked about it about couple of classes back terminal settling velocity is based on the stocks law. So, the throughput through this particular centrifuge is a function of the particle settling velocity which is the function of physical properties of the solid and liquid and the hardware and the operating conditions of the centrifuge; very simple we can say.

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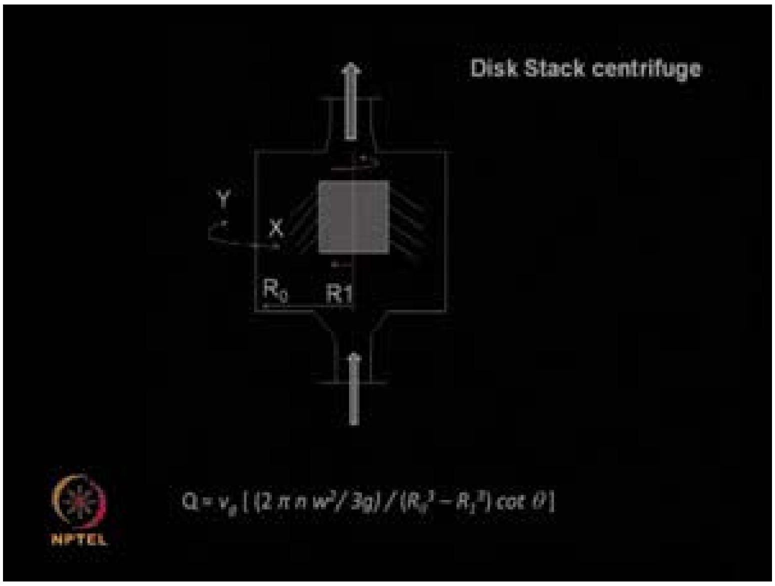

Now, let us look at the disk stack centrifuge again I talked about in previous class; this contains several disk act at certain angle. So, the liquid that enters from the bottom because of this disk get focused towards the outer periphery of the centrifuge; the solids get rigid stuck to the outer walls of the centrifuge whereas the liquid turns and then goes out here and the solids are collected here. So, the angle of the disk and the number of disks decides the efficiency of the centrifugal operation. And so let us not go into the derivation of this particular equation.

But ultimately you end with an equation of this form and again you see Q the throughput through the centrifuge is the function of V g; V g is the terminal settling velocity. And these are parameters which describe the hardware of this centrifuge and omega is your rotational velocity.

So, once again just like your previous relationships for bowls centrifuge we have the throughput as the function of the terminal settling velocity. And the hardware parameters whether it is a disk centrifuge or whether it is a bowl centrifuge we have throughput on the left hand side as the function of the terminal settling velocity and the hardware parameters. And the terminal settling velocity is once again a function of the physical properties of the solid as well as the physical properties of the liquid. So, very simple. So, it is directly related to the hardware parameters as well as the physico chemical properties of the liquid and the solid which you are trying to remember.

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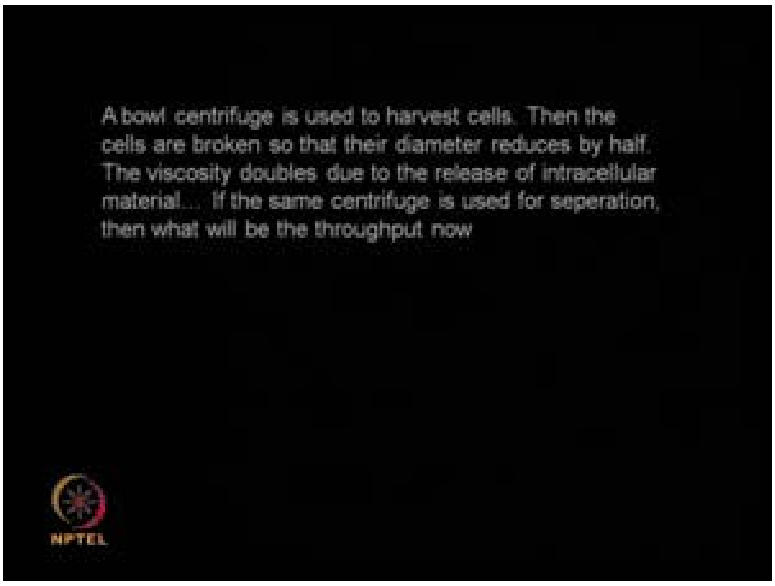

Let us look at the simple problem which tries to give you some idea about the throughput through a centrifuge. Imagine I am using a bowl centrifuge to harvest cells then what do I do is I take the cells break the cells. So, the diameter of the cells become half, the viscosity also doubles as I talked about it long time back the release of intra cellular material DNA, RNA generally rise the viscosity.

So, the viscosity is doubling and the particles have become half. And now I use the same centrifuge to again once again separate the solid and the liquid. So, what will be the throughput? So, initially I have the centrifuge where the particles are of certain diameter d and viscosity is of certain viscosity mu. Now, the diameter has become d by 2, viscosity has become 2 mu. So, what will be the throughput?

Now, you have to recall your stocks law if you want calculate what will be the throughput? Now, nothing is happening to the hardware I am maintaining same RPM of the and I am using the same centrifuge. So, nothing is happening to the hardware only the terminal settling velocity term changes. So, my throughput will be depending upon the parameters inside my terminal settling velocity. So, if you recall your equation throughput is the function of particle settling velocity and hardware.

And, I am not doing anything to the hardware I am just changing the settling velocity. Because the particle size has become half and the viscosity has doubled. So, you recall your stocks law you have the viscosity term here and the diameter is square term. So, viscosity has become 2 mu and diameter has become d by 2 square. So, the velocity from original value has been changed because the change in diameter as well as the change in viscosity. And that is going to affect my throughput which is on the left hand side.

So, what is going to happen because the particle has become down in size. So, viscosity the velocity will change in a squared fashion viscosity has doubled. So, again the velocity has going to change in the fashion. So, new throughput will be equal to old throughput because the particle have become half; I have put half square because diameter square term is coming here.

Now, viscosity has doubled. So, I put a 2 term in the denominator. So, look at 1 by 2 square become 1 by 4 there is a 2 here. So, it becomes 1 by 8. So, what happens? The new throughput has gone down by a factor of 8. So, old throughput divided by 8 because the particle has become smaller and the viscosity has doubled. So, what do we have to do? If you want to use the same equipment either you except that the throughput will go down or I have to change my RPM.

So, that I am able to increase my throughput; you might not be able to increase it by a factor of 8. But you may be able to increase it double it or triple it or an may have to go through some other bowls centrifuge. So, that I can maintain the same throughput. So, that is what normally is practiced; people do not use the same centrifuge and hope to get the same throughput. But they will like to go to some other equipment with the different dimensions or with different angular velocities.