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Unit Operations of Particulate Matter

Lec-04
Centrifugal Sedimentation and Equipment (Part - 1)

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Welcome to the 4th lecture of week 1 this is about centrifugal sedimentation and industrial equipment used for sedimentation process this particular lecture is divided in two parts that is lecture 4 and lecture 5 in lecture 4 I will speak about centrifugal Sedimentation and in lecture we will discuss industrial Equipment. So let us start with centrifugal Sedimentation. Now what is centrifugal Sedimentation the centrifugal force you all understand that it is?

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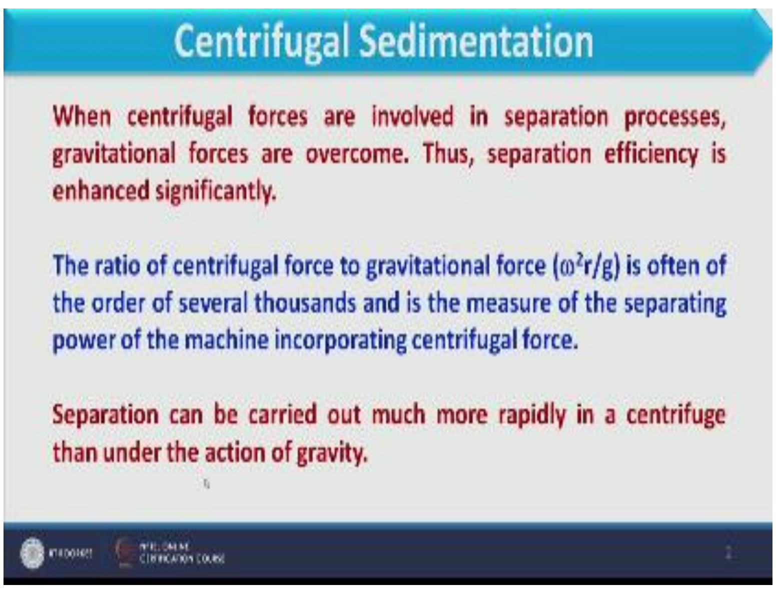

In radial direction so when centrifugal forces are involved in separation processes gravitational forces are overcome. Thus separation efficiency is enhanced significantly so what happens in centrifugal force that when we consider the sedimenter in usual sedimenter what happens the particle starts settling down however in centrifugal sedimentation what happens the equipment revolves with very high rpm.

So what happens the slurry which is available in that is collected that separated at the periphery of this due to centrifugal forces now if we have heavier particles as well as the if we consider the slurry which contains the solid particle as well as solvent so what happens solid particle will be because of because they are more heavy so it will be collected at the wall of the equipment.

However at the inner layer we have the clear liquid so in that way the separation occurs, so that is due to centrifugal action now if we consider the centrifugal forces as well as gravitational forces the centrifugal forces are very high in comparison in gravitational forces so the ratio of centrifugal forces to gravitational force that is ω^2 r is due to centrifugal force and g is due to gravitational force is often of the order of several thousands and is a major of separating power of the machine incorporating centrifugal force.

So what happens because this centrifugal forces ratio with gravitational force is very high the separation becomes very easy or very fast in comparison to centrifugal forces in comparison to normal sedimentation which works under gravity, so separation can be carried out much more rapidly in a centrifuge than under the action of gravity?

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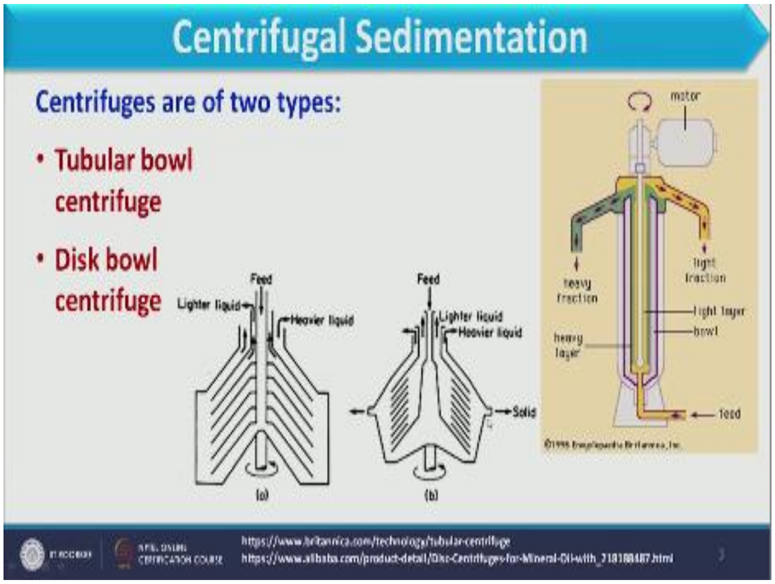

So as for as centrifuges are concerned these are of two type first is the tubular bowl centrifuge, tubular bowl centrifuge is shown in this diagram where here we have the smaller diameter however length is significantly high in comparison to diameter so in this case fed enters from the bottom and this total bowl revolves with very high RPM so what happens the fed which is coming into this camber that is inside the blow which is revolves.

So what happen the particle the heavier particle which due to centrifugal forces the heavier particles are collected and the periphery of this and forms a heavy layer now inside this we have the liquid layer which lighter than the particle so these are used for separation of solid and liquid as well as liquid which is one is having more density or we call at heavy liquid and second is lighter so it they are also used to separate liquid of different densities and slurry which is contains particles as well as solvent or liquid.

So at the periphery of this blow that is tubular bowl at the periphery of this heavy layer is formed due to the particle and which is collected at the top and litter liquid which is available inside the layer of heavy particles or heavy material the light liquid which is available that is collected from another path so here we have the heavier fraction as well as lighter fraction both are collected so what happens this is here we have feed enters from the bottom usually in sedimentation normal gravities sedimentation feed enters from the tope sometimes it also it enters from the bottom also in the sedimentation tank but here in tubular bowl it is always entered from the bottom so this is the tubular bowls centrifuge seconds into centrifuge we have is the disk bowl centrifuge which is shown in this diagram what happens in disk bowl centrifuge.

Here we have the bowl and inside this we have different we have many disk which are available one over another with the specific distance so what happens in this case feed enters from the top and this complete a send me that is the shaft were the disk are available these a send rotates so what happens feed which is coming from the top it is first divided into in two sections that is both side of the bowl as you can see in this diagram and when we when it is rotated so what happens the solid which is available in this that is collected over here or the heavier liquid which is available.

If we need to separate two liquids of different density so heavier one will be collected at the Perry ferry however lighter one will be transpose from these disk to the top so here another diagram we have this is again another example of the disk bowls centrifuge were liquid is collected from inner section of were disks are available and solid is and heavier liquid is collected at outer section of this disk were as lighter liquid is we have taken from the center.

Now solid which is deposited over here that we can take out so here we have basically the separation of solid liquid and separation of heavier liquid as well as lighter liquid so both can be separated in this and this disk bowls centrifuge as well as tubular bowls centrifuge both are used to separate the particles as well as heavy and height liquid.

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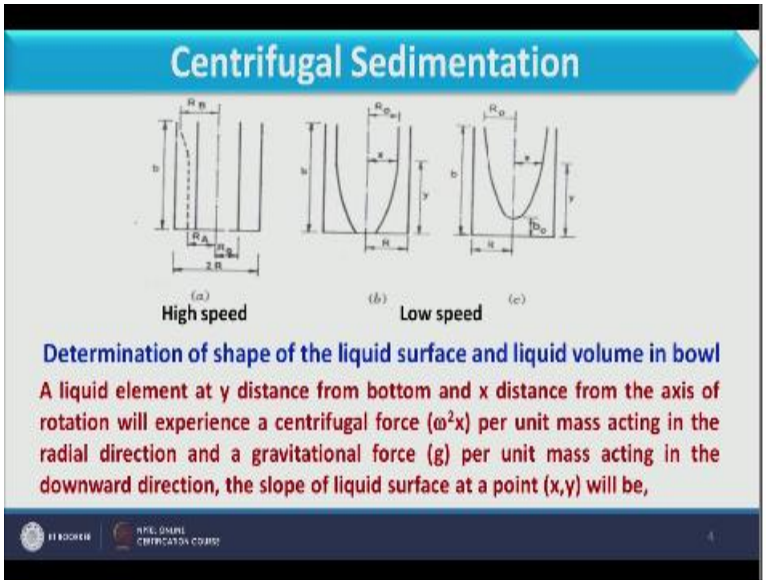

So here we have in centrifuge sedimentation they are going to derive the expression to calculate volume which is continue which can be contain in the bowl the residence time of the particle and we will again we will further define the cut diameter which speaks about that how much fraction or how much size of the particle can be separated and beyond that particle cannot be separated through centrifuge sedimentation so to start this so here we will discuss the shape of the liquid surface and liquid volume in the bowl.

Now to derive the expression first fall we should understand what type of trajectory is found is observed during the centrifugal action in bowled when centrifugal forces act or when a centrifugal action is taking place in a bowl the liquid is collected at the Perry ferry all liquid will be collected at the Perry ferry an form a vertex now what happens when speed of the when RPM is very high or when the speed of rotation is very high what happen liquid will be collected at the wall of the container.

Or wall of the bowl so when we consider a high speed you can see in this diagram you can see in this diagram which has radius are and total height has b now here you see this total after centrifuge what happens this we have the factor Ra as well as Rd which a speaks about the trajectory now in high speed when we consider high speed all liquid will be accumulated at the Perry ferry of the bowl so it will trajectory will start from R_A to R_B so at high speed this type of a profile will get however at.

Low speed the vertex forms a parabolic like trajectory parabolic like profile as shown in figure this as well as this in this diagram we have lesser a speed income barrage into this diagram so here we have proper parabolic however here it is parabolic is not formed completely and in this first figure at very high speed parabolic is not appear at all, so a liquid element at y distance liquid element at y distance if you consider this particular figure here we have why we are considering for height and x we are considering for radius.

So liquid element at y distance from the bottom that is this and x distance from the x is of rotation that is from the center, when experience a centrifugal force ω^2 x, now if we have the x distance and y at this point if any liquid element is available it will experience ω^2 x centrifugal force/unit mass in the radial direction as we have discussed the centrifugal force will act in radial direction so at this particular position the centrifugal forces/unit mass is ω^2 x.

However it will also act this element will have the experience of gravitational forces that is G per unit mass which will act downward so the slope of liquid at this particular point x and y that is at this point can be defined as dy.dx = ω^2 x/g.

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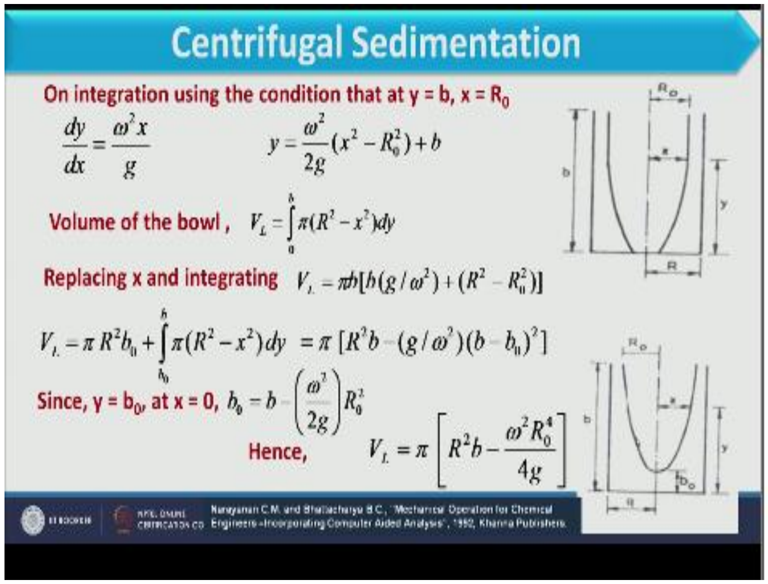

Now on integration using the condition that at y = b, x = R_0 so here we have y = when y = b that is at the top x should be R_0 so at this particular condition from here to here we will integrate so here we have this particular equation where $dy/dx = \omega^2 x/g$ when we integrate this while come putting the value y = b and x = R_0 we can find this particular equation where y is related with x^2 , now volume of the bowl how we will calculate volume of the bowl is.

VL is integrate from 0 to b$\Pi r^2 - x^2$ that is at particular point $r^2 - x^2$ that is for this particular section into dy, so that is the volume of the liquid in bowl so when we replace x^2 from this equation to this equation and integrate this equation from 0 to b we can get final expression of v_w final expression of VL as Πb(b (g/ ω^2) + R^2 – R0^2 so this is the expression of volume, now if this is the condition where we have the complete parabolic is formed.

After distance b0 from the bottom so in this case total volume of the liquid would be ΠR^2 B0 that is total volume of liquid available in this particular section and then we will integrate from B0 – bΠr^2 - x^2 dy, now you in this particular equation what happens that this expression we have integrated from 0 to b we can find this now if we replace this b by b-b0 because b0 $\rightarrow$ b is the limit of this particular expression.

So as this is the integrated part of this after integration we can find this expression where b we can replace where b-b0 and then the whole expression would be put over here in place of this and after solving this we can get the expression of VL like this, now here we have another factor that is B0 so since y = b0 at y = b0 x would be 0, so from this equation at y = b0, x would be 0 from this equation we can find b0 expression.

And while putting this b0 into this we can calculate total volume which is available in this type of container this type of centrifuge where volume can be in terms of all own parameter like bR0 ω etc, g ω all these we get fine so here using this expression we can calculate volume of the liquid which is available in bowl, so here we will discuss the centrifugal sedimentation where force balance will be discussed to calculate the residence time of the particle.

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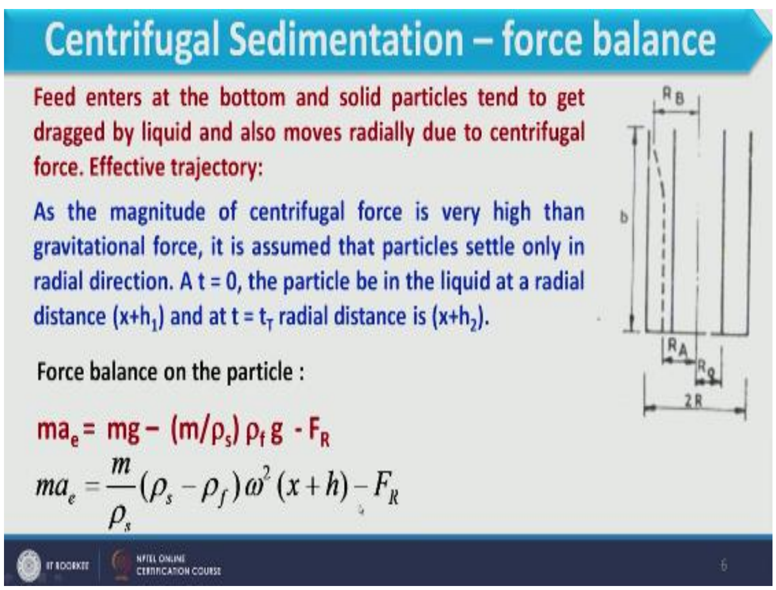

Now feed enters at the bottom and solid particles tend to get dragged by liquid and also moves radially due to centrifugal force. So effective trajectory would be like this as we have discussed previously. As the magnitude of centrifugal force is very high then the gravitational force it is assumed that particles settle only in radial direction, because centrifugal forces are higher so particle will be suspended in the liquid instead of settling down to at t=0 particle will be in a liquid at radial distance that is $x+h_1$.

For example, if $x+h_1$ over here at time equal to t it should be $x+h_2$ at this so this distance when we consider so that time required to move this distance would be the resistance time in centrifuge. So to calculate this we make the force balance on the particle and this is the net acceleration here we have this mg- that is due to weight of particle itself this is due to balance and this is due to rage forces.

Now as this equation is valid when gravidity force will act in this case as centrifugal forces dominate so we will replace g value with ω^2 x, so here ma_e would be equal to m/ρ_s ρ_s- ρ_f ω^2 (x+h)-F_R (x+h) is the distance at which particle is available in the solution. Now here we have different expression for F_R and we can define different conditions for laminar as well as turbulent flow.

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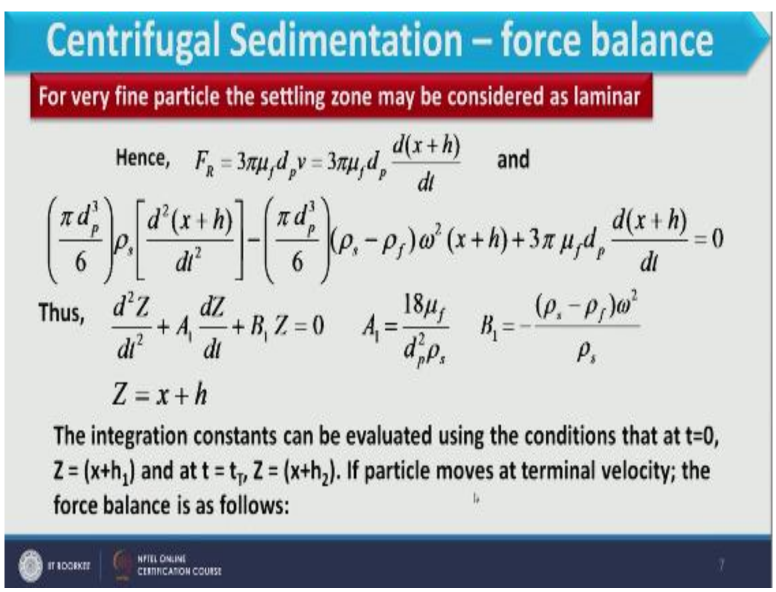

So if particle is very fine, very small the settling zone maybe considered as laminar in that case F_R can be defined by this expression where v is the velocity which can be replaced by d(x+h)/dt once we put this in the previous expression that is in the, here we have replaced m of the particle as volume of the particle into density and this is the acceleration term and here the same m we have replaced and rest parameter are as it is and F_R we have kept like this.

So this is the equation while putting all expressions so further we have redefine the equation in terms of Z where A_1,B_1 and Z are defined in this way. So the integration constant can be found at considering the case that at t=0 Z should be x+h_1 and at t_T Z should be x+h_2, so if particle moves with the terminal settling velocity what is the meaning of this that at terminal settling velocity there will not be any net force which is acting on the particle so net acceleration would be in that case 0, so when we neglect this particular term because it is 0 and while solving these two expression we can get the equation like this.

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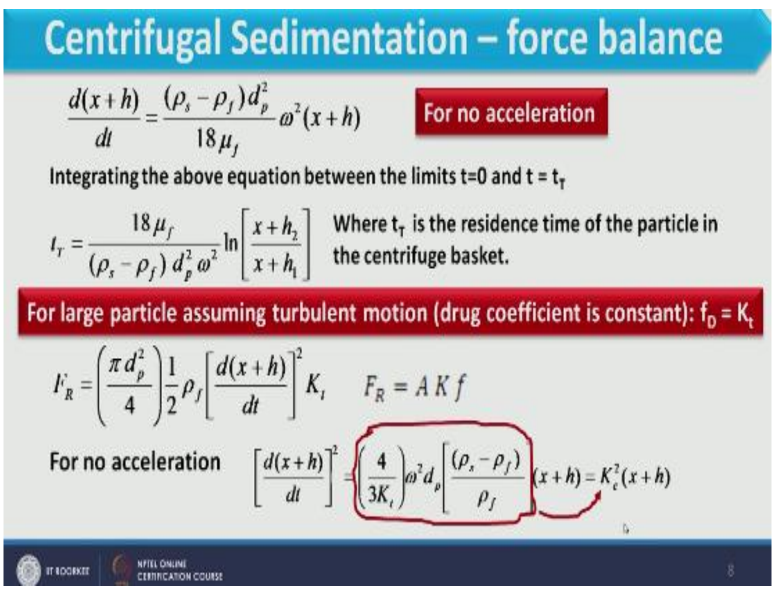

That is d(x+h)/dt in this form so that is the case when no acceleration is applicable. Integrating above equation from t=0 to t=t_T we can find the residence time of the particle in the centrifuge so where t_T is the residence time of the particle in the centrifuge. Similarly if we have larger particle we assume a turbulent flow where drag co-efficient is we are considering as k_T so this is the equation for F_R that is F_R=AKf A is the projected area of particle K is the kinetic energy per unit volume of the particle and f is the drag co-efficient that is kT in this case.

So while putting this F_R where you can get like this again for no acceleration condition we can find this expression where the whole parameter, whole expression is converted into K_C^2.

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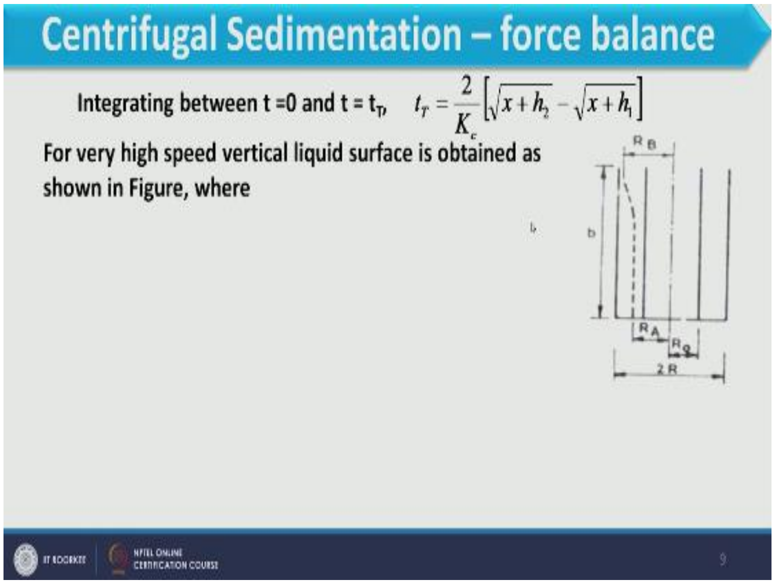

So in that case again while integrating we can get residence time of the particle in this form, further for very high speed vertical liquid surface is obtained as shown in the figure like here we have the this way so in that case initial $x+h_1$ should be RA and $x+h_2$ should be RB, so while for this case when we consider we have residence time of particle for laminar zone this so here this all this we will replaced with R_A and R_B.

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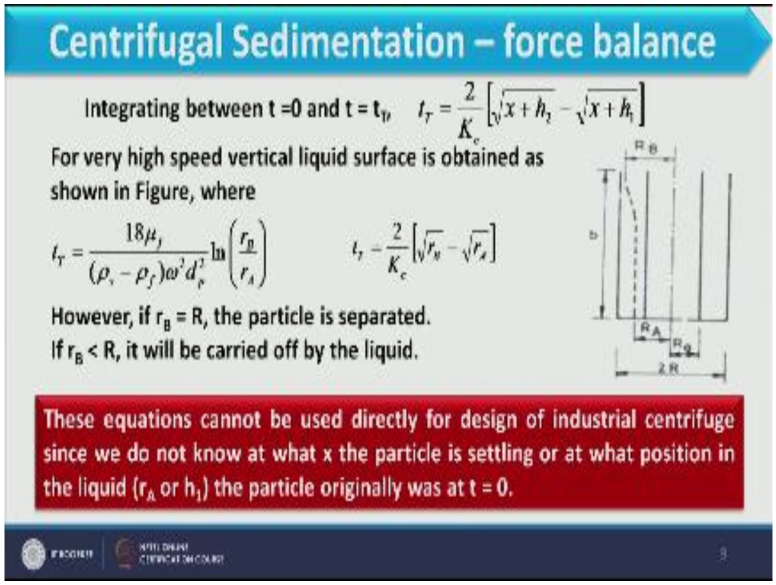

And similarly for turbulent flow we can replace this and this as R_B and R_A so after replacing this we can final residence time for the turbulence zone for the laminar zone as well as turbulent zone. However these equation cannot be use directly for design of industrial centrifuge since we do not know at what X the particle is settling or at what position in the liquid are A_R H_1 the particle originally was at T = 0.

Now if R_B in this particular equation if R_BN = R when we are considering so the particle is separated, so when T_B = R that is it should be ate the vale we consider the particle to be separated, however when RB < R it will be carried with the liquid. So these are the residence time expressions we can also find residence time alternatively like considering total volume.

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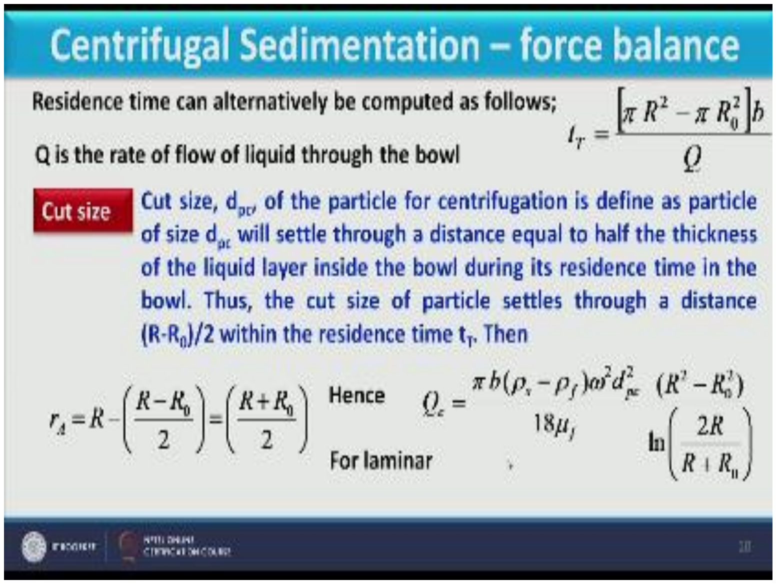

Which is volume of the liquid in the bowl divided by the flow rate that volumetric flow rate duration of these two will give the residence time where Q is the rate of flow of liquid through the bowl and here we have to defined one parameter that is very important parameter and that is called as the cut size the cut size we can denote as D_{PC} of the particle for centrifugation and it is define as the particle of size D_{PC} will settle through a distance equal to ½ the thickness of the liquid layer inside the bowl.

During its residence time in the bowl thus the cut size of the particle settles through a distance R – R_0 / 2 within the residence time T_T, so what is the meaning of this that when residence time when we consider the cur diameter of the particle it means it will settle at this distance so particle which is lesser than the D_{PC} that will not be settle and particle which are higher in size then D_{PC} will be settle because they will moved in this particular distance.

In that case R_A should be R – R_0 / 2 so this is the total distance total radios of the bowl and this is the distance they will move so while solving this we can consider this particular expression where R_A, so R_A is nothing but the distance of half of the layer it will be RA and Rb would be the R in that case if we considered the cut diameter.

So for laminar zone we can calculate Q_C like this and now how this expression we have obtained is we have this Q value and this Q_C we have defined here if you consider the previous slide her we have the T_T expression once we put T_T expression in this and then solving it for Q we can obtain the equation like this.

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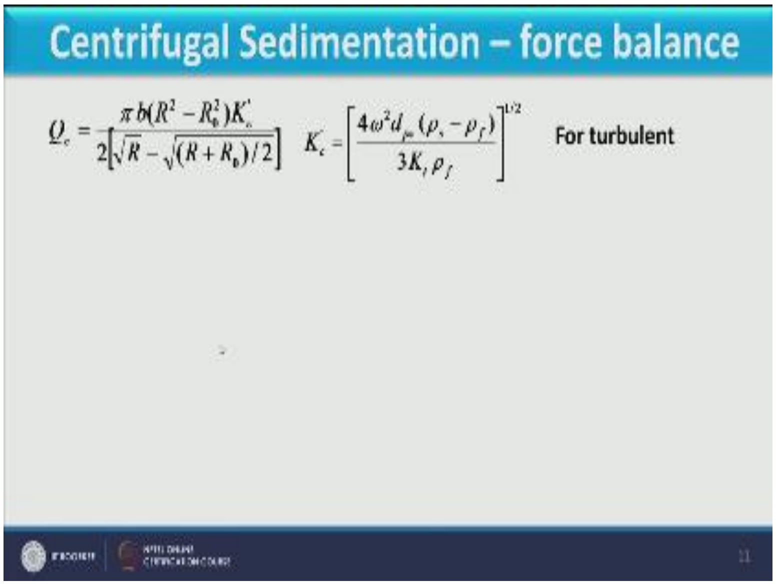

Similarly for turbulent zone we have this expression where K_C' we can define like this so how we can defined these equation because we have already residence time in laminar zone as well as in turbulence zone so that expression we have put to calculate the q value because we have two expression to T_T and then we can replace and then calculated Q for laminar as well as turbulent.

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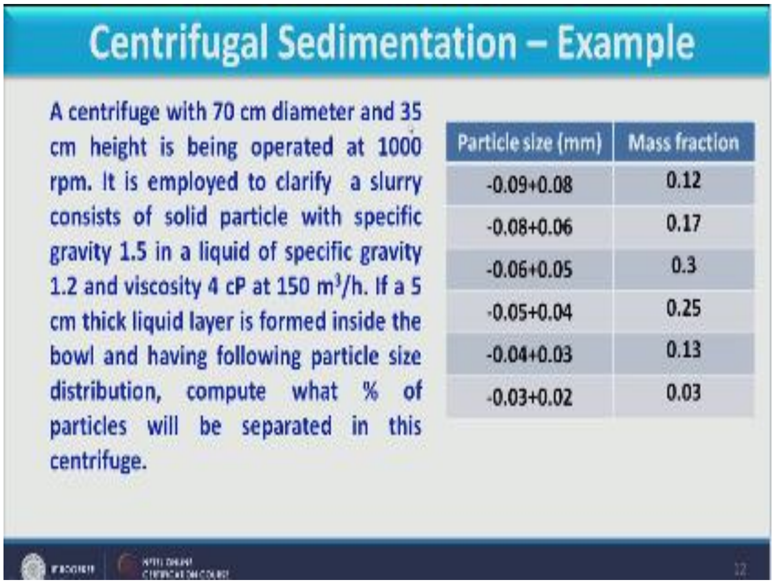

So here we have the example of centrifugal sedimentation where a centrifuge with 70cm diameter and 35cm height is being operated at 1000rpm. It is employed to clarify a slurry consists of solid particle with specific gravity 1.5 in a liquid of specific gravity 1.2 and viscosity 4cp at $150m^3/h$, if 5 cm thick liquid layer is formed inside the bowl and having following particles size distribution compute what percent of particles will be separated in this centrifuge.

So here we have the problem and the particle size data will be available over here that particle size minus and plus and all fraction which is available on this particular screen. So we have use this data we have calculate the percentage of particle size which can be separated so first of all what we have calculate is the all flow rates we know that is the Q value we know so we can calculate the cut diameter of the particle and we will see that how many particles are available above to this.

So all those particle percent of particle will be separated and particle which are lesser than the cut diameter that should not be separated, so first of all we have to calculate the cut diameter.

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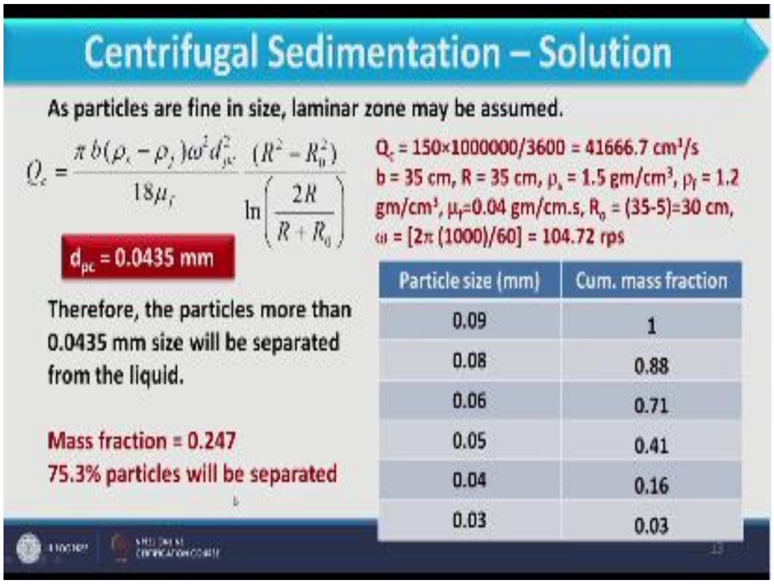

So here we have the particle as the particle size is very small here you can see the particle size the maximum can be 0.09 and minimum is 0.02, so that is particle size is very small so we can consider this as laminar zone. Qc expression for laminar zone is this that is just we have discussed. So here we have d we have replaced dpc that is the cut diameter.

So here we have Qc value which is 150mq/hr that is given, so we can represent this in cm^3 per sec $bR\rho S\rho F\mu FR_0$ how we will calculate total radius of the bowl we know and we know the 5cm layer is formed so total R_0 should be outer edge and starting of the distance x and starting distance of layer that is the 5cm thick layer is there, so 35cm is the radius R_0. So how R_0 we will calculate is R- thickness of the layer.

So R is basically the radius of the bowl which is 35cm and 5 cm thick layer is formed inside, so R_0 will be 35-5 that is 30cm. ω we can calculate because 1000rpm is given to us, so once we calculate once we put all this value into this and calculate dpc that dpc can be found as 0.0435mm. Now we are given the particle size distribution data that we will represent in the cumulative form to see how many particles are available which is having the size greater than the dpc that is 0.043.

So to do this we can have the cumulative value in this table where all values size values are available and fraction we will be keep on adding because it is cumulative, so here we can see this cut diameter is 0.0435mm which lies in-between these two. So once we calculate corresponding to this the total fraction we found is 0.247, so 0.247 will lie below dpc ,so 1-.247x 100= 75.3% particle will be separated because their size would be greater than the size of the cut diameter per which we just calculated.

So in this particular example 75.3% particle will be separated so in this way we can derive the equation center figure sedimentation and we can use this for the calculation purpose and calculate how many part5icles are available etc. so that is all about center figure sedimentation. So for this session we have to stop over here in next session we will continue with and we will discuss the industrial equipment available for sedimentation, so that is all for now. Thank you.

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