Mechanical Unit Operations
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Lecture 27
Principles of Cake Filteratoin-2

Welcome to MOOC's course, Mechanical unit Operations, in the previous lecture of this course, we have seen principles of cake filtration under the constant pressure filtration as well as the constant filtration rate process conditions as well. So, within the constant pressure filtration case we have seen, what are the governing equations for the batch process as well as the continuous process and for the continuous process, continuous flow rate or continuous volumetric flow rate process we have seen a corresponding equations on governing equations as well.

So, now, in this particular lecture, we are going to have a kind of a few example problems both for batch and continuous pressure filtration processes. And then we discuss some details about the centrifugal filtration processes followed by problems on centrifugal filtration processes.

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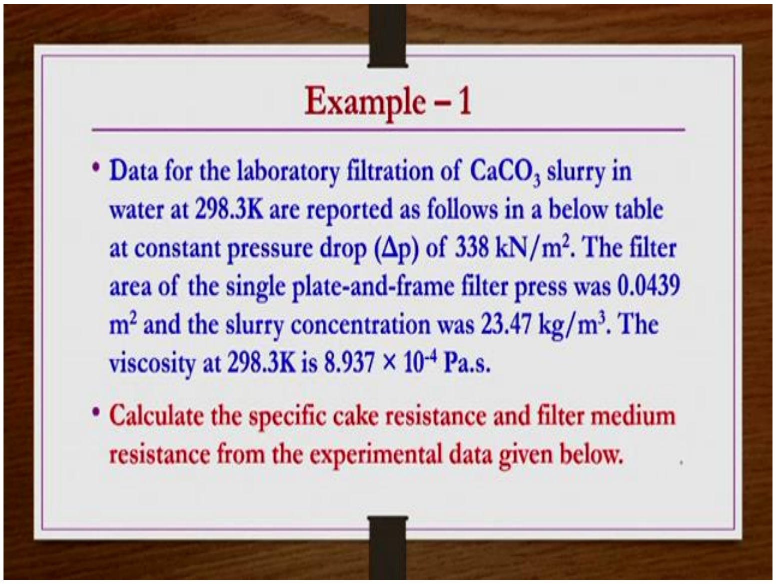

So, let us take example number one, so, data for the laboratory filtration of calcium carbonate slurry is in water at 298.3 K are reported as follows in a below table at constant pressure drop off 338 kN/m^2, the filter area of the single plate and frame filter press was 0.0439 m^2 and then slurry concentration was 23.47 kg/m^3.

The viscosity at this temperature is 8.937 x 10^{-4} Pa-s. The table data is given in the next slide. So, calculate the specific cake resistance and filter medium resistance from the experimental data given below in the next slide. So, the first problem is about to how to calculate the filter medium resistance as well as the specific cake resistance under constant pressure filtration conditions.

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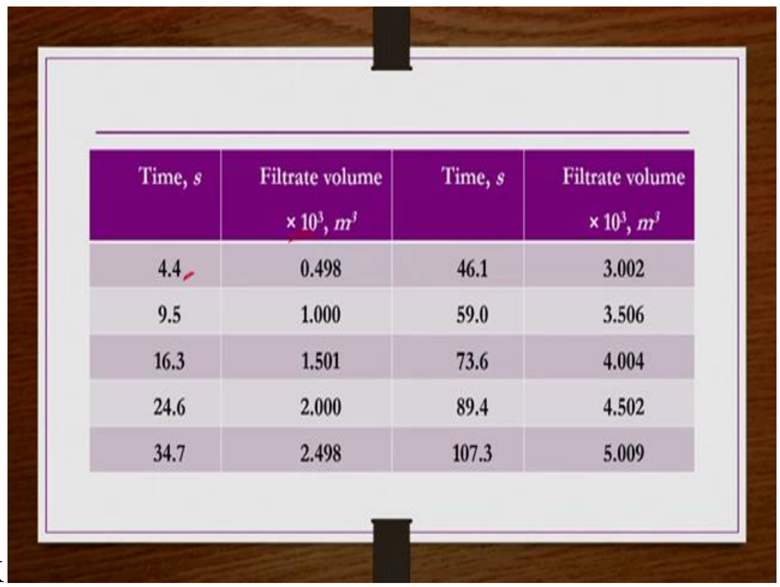

Time, s	Filtrate volume $\times 10^3$, m^3	Time, s	Filtrate volume $\times 10^3$, m^3
4.4	0.498	46.1	3.002
9.5	1.000	59.0	3.506
16.3	1.501	73.6	4.004
24.6	2.000	89.4	4.502
34.7	2.498	107.3	5.009

K

The experimental data time versus filtrate volume collected is given here. So, filtrate volume is now here multiplied by 10^3 so, that means 0.493 that means, 0.498 x 10^{-3} m^3 of filtrate volume would be collected by time 4.4 sec. So, like that the filtrate volume at different time levels are given here, at different time intervals are given here.

So, this information we have to use basically t versus V information is given. So, we have the equation $\frac{t}{V} = \left(\frac{K_c}{2}\right)V + \frac{1}{q_0}$ and then $\frac{t}{V}$ versus V, if you plot you will get a kind of a straight line with slope $\frac{K_c}{2}$ using this K_c value you can get the specific cake resistance and then intercept of this line would be $\frac{1}{q_0}$ and then using this $\frac{1}{q_0}$ intercept value you can calculate the filter medium resistance that is R_m. That is what the process that we are going to follow in order to get α and R_m values as required by the problem.

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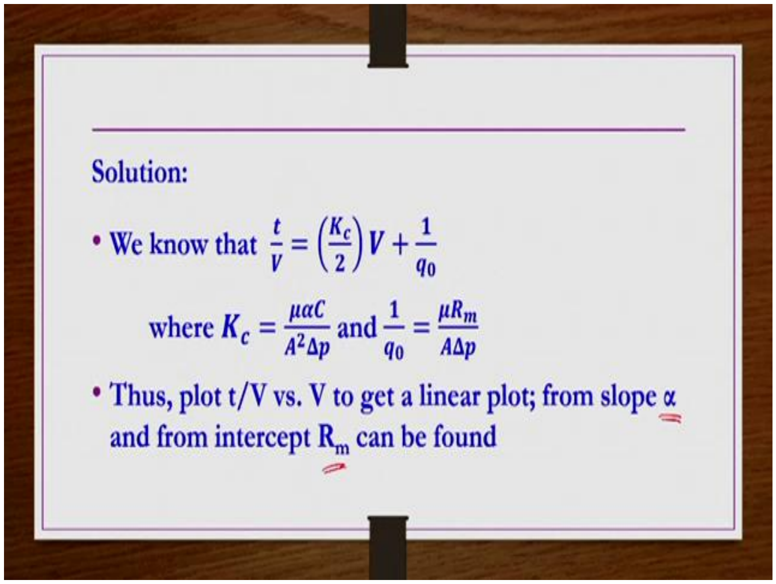

So, we know that $\frac{t}{V} = \left(\frac{K_c}{2}\right)V + \frac{1}{q_0}$and then $K_c = \frac{\mu\alpha C}{A^2\Delta p}$ and $\frac{1}{q_0} = \frac{\mu R_m}{A\Delta p}$. So, in this equation everything is known, so, plot $\frac{t}{V}$ verses V. So, that you get a linear plot and from slope α can be calculated and from intercept R_m can be calculated.

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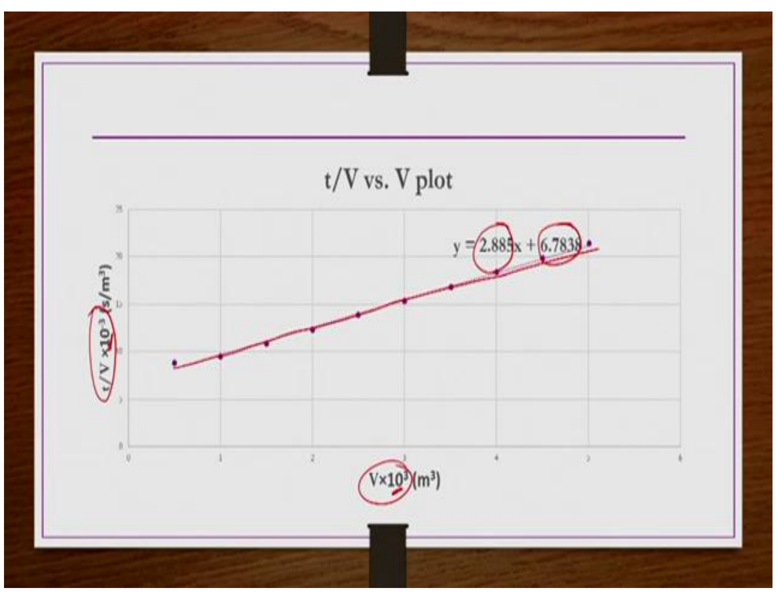

So, let us rearrange the data $\frac{t}{V}$ versus V and then if you plot the data you will get a kind of straight line like this. So, this $\frac{t}{V} \times 10^{-3}$ versus $V \times 10^{-3}$ is there. So, whatever the slope that you will get, that slope has to be multiplied by 10^{-6} and then whatever the intercept is there that should be multiplied by 10^{-3} because of this 10^{-3} here and 10^{-3} here. So, this $\frac{t}{V}$ versus V, the plot is like a linear plot where in the form of $y = mx + c$, slope is 2.885 and then intercept is 6.7838.

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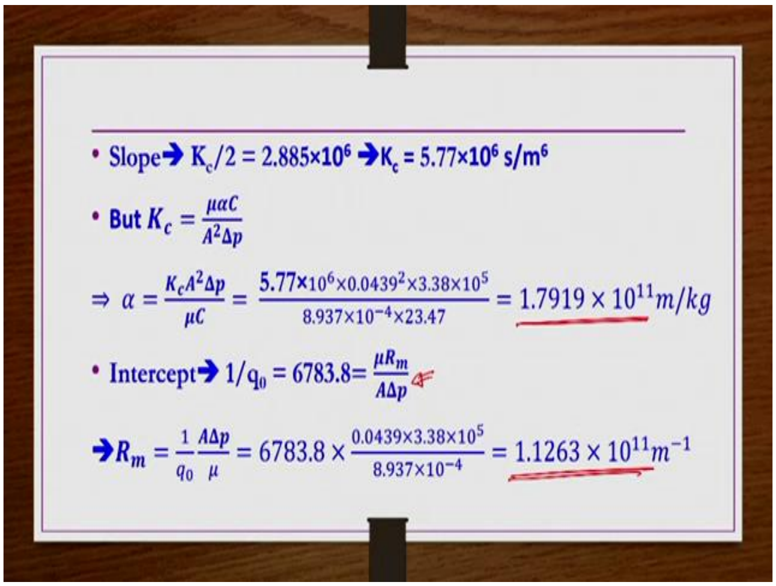

So, from here, slope $\frac{K_c}{2}$ is equal to 2.885 and that should be multiplied by 10^{-6} then K_c is nothing but 5.77 x 10^{-6} s/m^6, but $K_c = \frac{\mu\alpha C}{A^2\Delta p}$. So, in this expression except α everything is known. So $\alpha = \frac{K_c A^2 \Delta p}{\mu C}$ so, Kc just now we found it as 5.77*10^6, A is nothing but 0.0439 and Δp is nothing but 3.38 x 10^5 Pa divided by μ is 8.937 into 10^{-4} Pa-s and then c is given as 23.47.

When you calculate simplify this expression you will get all α as 1.7919 x 10^{11} m/kg. Similarly, intercept $\frac{1}{q_0}$ is 6.7838 but that should be multiplied by 10^3, when you multiply by 10^3 you will get 6783.8 and then that $\frac{1}{q_0}$ is nothing but $\frac{\mu R_m}{A\Delta p}$ and then from here you can get R_m as $R_m = \frac{1*A\Delta p}{q_0\mu}$, substitute all the value simplify. So R_m value you will get 1.1263 x 10^{11} m inverse, so this is about the first problem.

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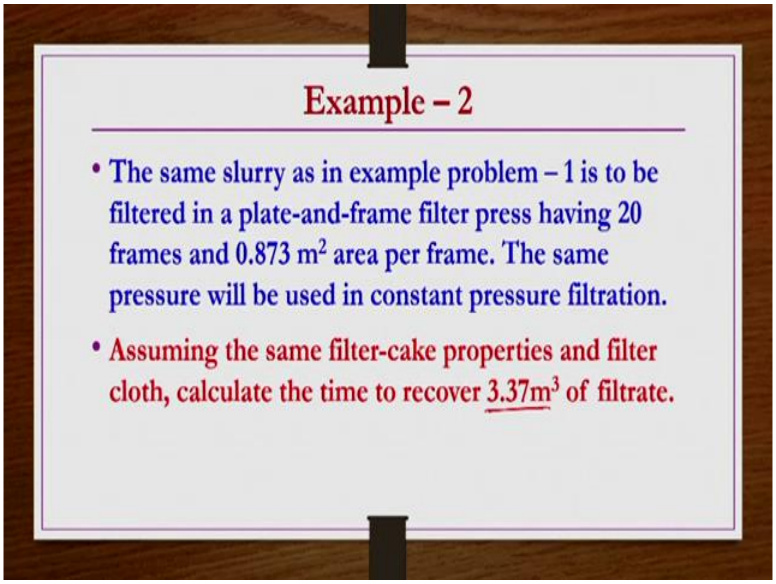

Now, example two, the same slurry as in example problem one is to be filtered in a plate and frame filter press, this one type of you know filtration equipment we are going to see in the next lecture, having 20 frames and 0.873 m^2 /frame. The same pressure will be used in constant pressure filtration as in example number one. Then assuming the same filter cake properties and filter cloth, the filter medium properties calculate the time to recover 3.37 m^3 of filtrate basically, all the conditions are exactly same as in the previous problem except the area, filtration area has been changed, filtration area earlier it was 0.0439 m^2.

So, now here we are using plate and frame with 20 frames, each frame is having 0.873 meter squared area. So, the overall filter area would be 0.873 x 20, further it mentioned that everything is same as in the example number one. So, α and R_m etc will also be same as in example number one, but then what is change? Change is area, if area is changing according to new area what is the K_c? Slope what is the intercept $\frac{1}{q_0}$ that you have to modify and then from there you further make use of the same equation to get the time required to get 3.37 m^3 of filtrate.

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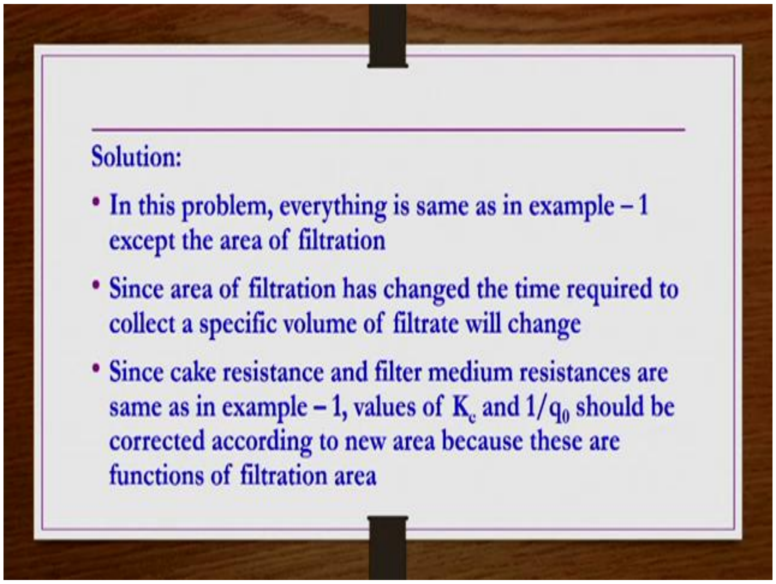

That is, in this problem everything is same as in example one except the area filtration is changing. Since area filtration has changed the time required to collect a specific volume of filtrate will also change. Since cake resistance and filter medium resistance are the same as an example one values of K_c and $\frac{1}{q_0}$ should be corrected according to new area because these are functions of filtration area, how they are functions of filtration area that we see.

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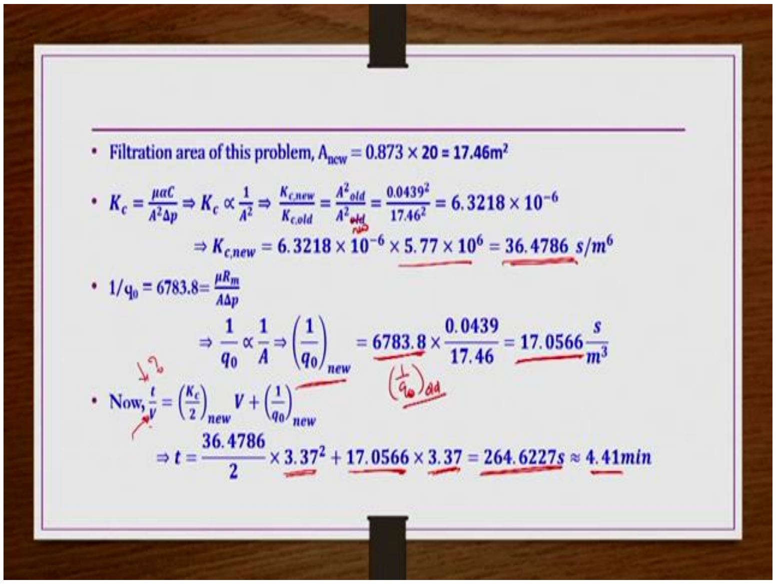

Filtration area of this problem is you know a new issue designated as a kind of new is 0.873 per press and then there are 20 such presses so, multiply by 20 you get 17.46 m^2, then K_c we have $\frac{\mu\alpha C}{A^2\Delta p}$ so that means K_c is inversely proportional to A^2. So K_c for new area, if you wanted to calculate and you designate it as $K_{c_{new}}$ so, then we have $\frac{K_{c_{new}}}{K_{c_{old}}}$, old stands for now, for the previous problem example one.

So $\frac{K_{c_{new}}}{K_{c_{old}}}$ old should be $\frac{A^2_{old}}{A^2_{new}}$, A^2_{old} ld and previous example what is the area? $(0.0439)^2$ of it divided by new area for this problem is 17.46^2 of it, when you do it, you will get 6.3218 x 10^{-6}, if you multiply it by K_c of example one, previous told example K_c that is 5.77 x 10^{-6}, then you will get $K_{c_{new}}$ as 36.4786 s/m^6. So much it has decreased, in the previous case it was out of 10^6 now, it is order of 10^2 only.

Similarly, $\frac{1}{q_0}$ in the previous case 6783.8 that is nothing but $\frac{\mu R_m}{A\Delta p}$ so, what we understand from here $\frac{1}{q_0}$ is inversely proportional to filtration area. So, that means, if you wanted to calculate $\frac{1}{q_0}$ for as per the new filtration area $\frac{1}{q_{0_{new}}}$ should be 6783.8 that is $\frac{1}{q_0}$ of previous example problem, this is $\frac{1}{q_{0_{old}}}$ that is example one value, multiplied by old area, the previous problem area 0.439 divided by this problem filtration area 17.46 then you will get 17.0566 s/ m^3.

As a kind of $\frac{1}{q_{0_{new}}}$ or $\frac{1}{q_0}$ for this case, it also substantially changing, like previous case it was order of 10^3 to 10^4 now, here it is order of 10^2 only, 10^1.

So, accordingly the time would also be very much different to collect required volume. So, now, we have this equation $\frac{t}{V} = \left(\frac{K_c}{2}\right) V + \frac{1}{q_0}$. So, now, here $\frac{K_c}{2}$ and then $\frac{1}{q_0}$ they should be used for the kind of new conditions, that this new filtration area and then v is given to collect certain value of v how much time is required that you can calculate now from this equation so, t is equals to whatever this new K_c value 36.4786/2 and then V 3.37 m^3 volume if you wanted to collect. So, whatever the left hand side is there we are taking to the right hand side so, there will be V^2 for the first term and then second term it will be multiplied by V. So, $\frac{1}{q_0}$ t for new K_c is 17.0566 multiplied by v is 3.37 so, that comes out to be 264.6 second which is closely 4.41 minutes. Now, you can compare both the cases, in the previous case in the example in order to get 3.37 m^3 of volume of filtrate you have to give only less time whereas here it has to be large time 4.41 min. Likewise, this comparisons one can make.

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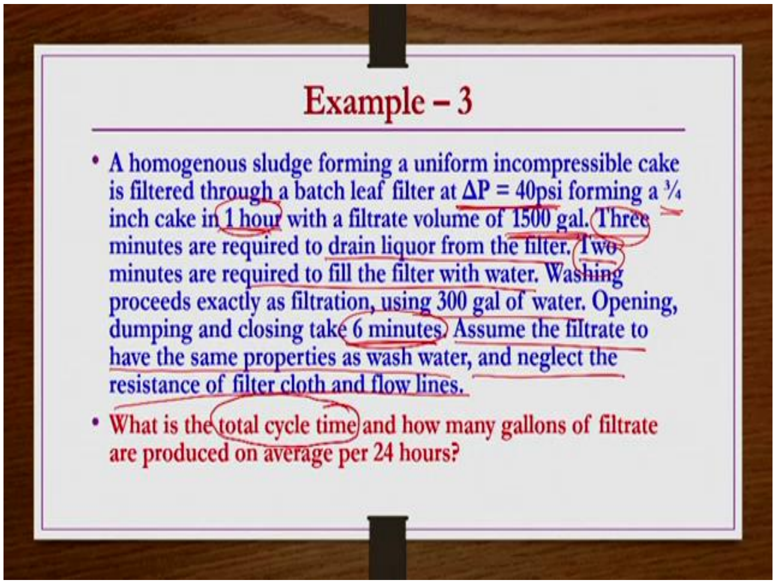

So, now example 3, you take a homogeneous sludge forming a uniform incompressible cake and is filtered through a batch leaf filter at Δp 40 psi and then forming a 3/4 inch cake in one hour with a filtrate volume of 1500 gallons. So pressure drop is given, filtrate volume is given, cake thickness is also given 3/4 inches and then filtration time is also given as one hour, further 3 min are required to drain the liquor from the filter and then 2 min are required to fill the filter with water. This is about washing process, washing is also include, washing proceeds exactly as in filtration process using 300 gallons of water.

So, opening, dumping and closing of this filtration process takes approximately 6 min. So, assuming the filtrate to have the same properties as wash water and neglect the resistance of filter cloth and flow lines and that is R_m is negligible. What is the total cycle time and how many gallons of filtrate are produced on average per 24 h that is the question, total cycle time, this total cycle time is the total time for the filtration, total time for the washing and then total time that is there for individually draining the liquor filling water etc those kind of things.

So, all the time should be added together to get the total cycle time, filtration time is also given one hour, but washing time is not given. so, we have to find out the washing time. So, once you find out the washing time add that time to all these filtration time of 1 h and then draining of liquor 3 min and then filling the filter with water 2 min and then closing, dumping, opening etc 6 min. If you add together all the time you will get the cycle time.

So, in order to know the cycle time you need to know wash time also that is what you need to calculate, but washing proceeds exactly same as the filtration that is also given. So whatever the constant pressure filtration process equations are there $\frac{t}{V} = \left(\frac{K_c}{2}\right)V + \frac{1}{q_0}$ those equations we can use here also, because washing proceeds exactly same as a kind of filtration and then filtration is at constant pressure of 40 psi. further in this equation, most of the things are given in a kind of FPS units. So what we will be doing, we will be solving this problem in FPS units.

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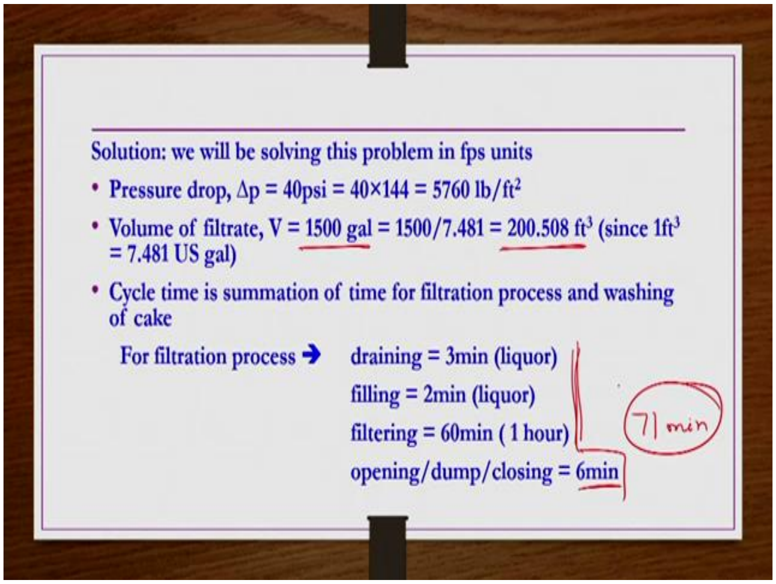

So, Δp is 40 psi that has to be in kind of, it will be a mask for ft^2. So, that has to be lb/ft^2, so, inches are there and 40 per $inch^2$, so, 1 inch is, 1 ft is nothing but 12 inches. So, feet square should be 144, So, 40 has to be multiplied by 144 so, then you will get Δp as 5760 lb/ft^2, this is simple conversion from psi to lb/ft^2, volume of filtrate is given as a 1500 gallons, but 1 ft^3 is equal to 7.481 gallons, especially US gallons, actually these conversions, gallon conversions are different for UK and US.

So, let us take US gallons conversion so, according to US gallon conversion 1 ft^3 is nothing but 7.481. So, when you do the conversion you will get V as 200.508 ft^3, cycle time is summation of time for filtration process and washing of cake along with another time of draining, filling kind of thing and then dumping, closing kind of time whatever the times are there are those times are included or added together to get the cycle time.

So, filtration process draining is the 3 min and then filling is 2 min. Filtering is done for 1 hr so, 60 min, so, 65 min and then opening, dumping and closing is 6 min so, 71 min is taking per filtration process, 71 min for the filtration process,

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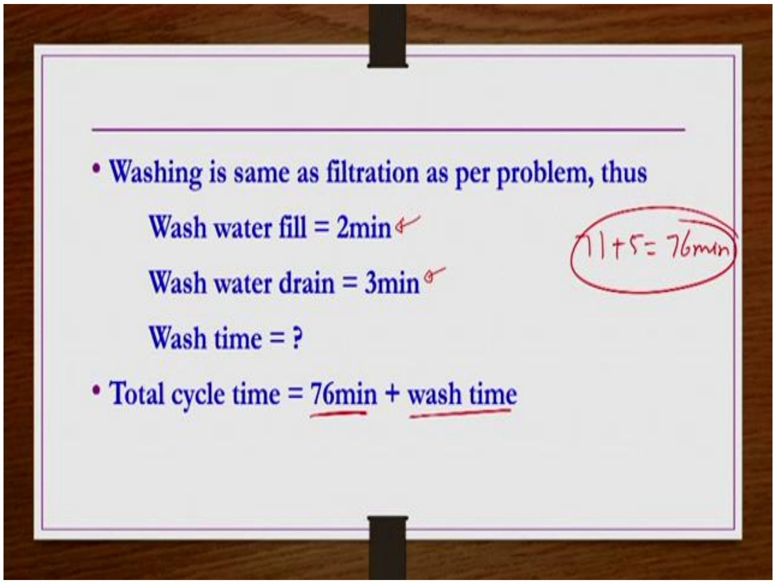

But we should also include the washing time also, in the washing wash water filling is required so, that is 2 min given, wash water drain and so draining time is 3 minutes because whatever the filtration is there the same way washing is also taking place so, for the filtration whatever the draining or filling times are the same time should be taken for the washing also. So, 71+5=76 min till now on this time. So, and wash time that is not given so, we have to find out. So total cycle time is going to be 76 mins plus, wash time if you find the wash time first part of the question would be done.

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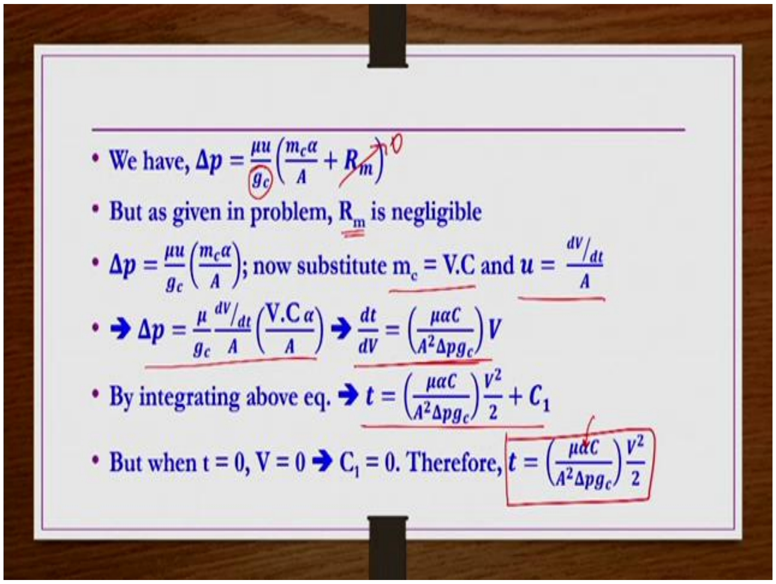

How to do? So, we have this equation Δp is equals to $\frac{\mu u}{g_c}\left(\frac{m_c\alpha}{A} + R_m\right)$ so, now we are using FPS unit since FPS units are using so, then this wherever the forces are involved the conversion g_c has to come into the picture like this. So, g_c is having 32.17 this ft/s^2 units. So, it is similar like in a conversion for acceleration due to the gravity kind of things. So, but as given in the problem R_m is negligible, so, you can strike out this part is negligible it is given in the problem.

So, this equation further now you can write is $\Delta p = \frac{\mu u}{g_c}\left(\frac{m_c\alpha}{A}\right)$. So, m_c you can write V.C and then u, you know it as $dV/_{dt}$ divided by the filter area A. So, now if you substitute this thing here you get Δp is this one and then you rearrange this equation such a way that $dV/_{dt}$ is one side and all other times are other side. So, this equation by integrating above equation what you get $t = \left(\frac{\mu\alpha C}{A^2\Delta p g_c}\right)\frac{V^2}{2} + C_1$. So, but $t = 0$, $V = 0$, because there is no filtrate collected at t is equal to 0. So, then constant C_1=0 so, then what we have this $t = \left(\frac{\mu\alpha C}{A^2\Delta p g_c}\right)\frac{V^2}{2}$, so if right hand side of this equation if everything is known, then we can use this equation straightforward to get the wash time. But here α is not known and then μ is also not given, C is also not given, A is also not given. So, what we have to do? We have to do some mathematical steps in order to avoid requirement of these things.

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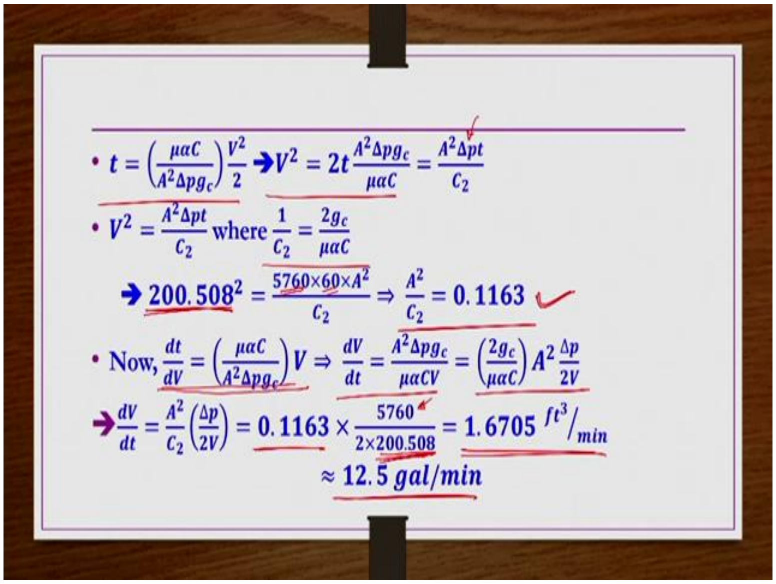

So, for the filtrate what it is given in order to get 1500 gallons so, before that one what we do the same equation we rearrange like V^2 one side and then all other times other side and then right hand side terms Δp t which are known, so, these things we keep as it is and then rest all other terms A^2 Δp t terms we retain as it is and rest all other terms we can write it as $\frac{1}{C_2}$ that is $V^2 = \frac{A^2 \Delta p}{C_2}$ where $\frac{1}{C_2}$ is nothing but to $\frac{2g_c}{\mu\alpha C}$ which is not known, mu is not known, Alpha is not known, C is not known. So that we are taking as a some constant $\frac{1}{C_2}$.

Now, but for the filtrate 1 h filtrate and 1500 gallons that is given, that is given. So, V for the filtrate and filtration process is given 1500 gallons when we converted it to the feet cube it has come as 200.508 ft^3 so V^2, the square of this value is equal to A^2, A value we do not know, C_2 we do not know, Δp it is given 40 psi, in lb force/ft^2 it is 5760 and then filtration time t is also given 1 h. So, that we write as 60 min, because cycle time we are writing in minutes so that is the reason.

So, from here $\frac{A^2}{C_2}$ how much you will get? 0.1163 so, unknown whatever the things are there $\frac{A^2}{C_2}$ that you have calculated from filtration information, in 1h filtration you get 1500 gallon that is given. Now, this value you can make use for wash liquid so, but this equation dt/dV is equals to the same equation, previous equation when you remove the R_m value you rearrange this equation like this so, then you will get dV/dt is equal to this equation and this $\frac{2g_c}{\mu\alpha C}$ is nothing but $\frac{1}{C_2}$.

So, when you write dV/dt is equals to $\frac{A^2\Delta p}{C_2 * 2V}$, $\frac{A^2}{C_2}$ you just calculated as 0.1163 and then Δp is 5760 lb/ft^2 and then V is nothing but 200.508, when you substitute all this tings volumetric flow rate you will get 1.6705 ft^3/min. This is again for the filtration; this is again for the filtration because we have used volume of filtrate collected here. So, filtration on is there and whatever the volumetric flow rate of filtrate is there that is 1.6705 ft^3/min.

If you convert it into the gallons because it is given in gallons, so it comes out to be 12.5 gallons/min. Because in 1 h 1500 gallons, you are getting that then per minute how much you get? 12.5 gallons/min to get any way, that same thing by calculation. So, this information we will be using in order to get the washing time.

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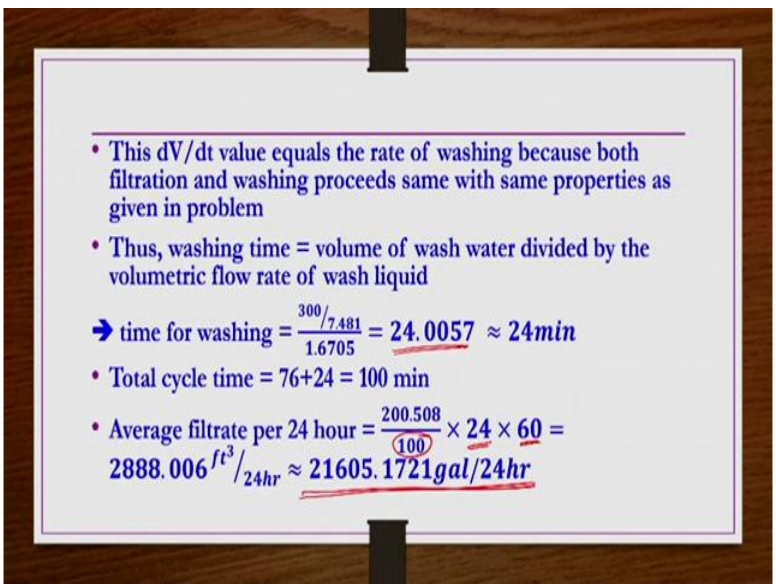

So, this dV/dt value equals the rate of washing because both filtration and washing proceeds same way with properties as given in problem one. So, this washing time should be volume of wash water divided by the by the volumetric flow rate of wash liquid. So, time for washing is 300 gallons of water is used for washing. So, 300/7.481 gallons if you do that will be ft^3 of water required dividing by volumetric flow rate of wash liquid is nothing but volumetric flow rate of the filtrate because both of them are proceeding same way.

So, volumetric flow rate of filtrate we already calculated as 1.6705 ft^3 /min so that comes out to be 24.0057 so, that is approximately 24 min, that means total cycle time is nothing but 76+24=100min, now average filtrate per 24 h is required, the second part question, so, filtrate volume is 200.508 ft^3 /min and then cycle time is now 100 min.

So, but we need in per 24 h so, if you multiply by 60 that will be per hour and then further multiplied by 24 that would be per 24 h. This is the second part of the question so, that comes out to be 2888.006 ft^3 /24 h and then if you convert this one into gallons it will be 21605 gallons/24 h. This is the average filtrate that you get, per 24 h of process time, filtration time.

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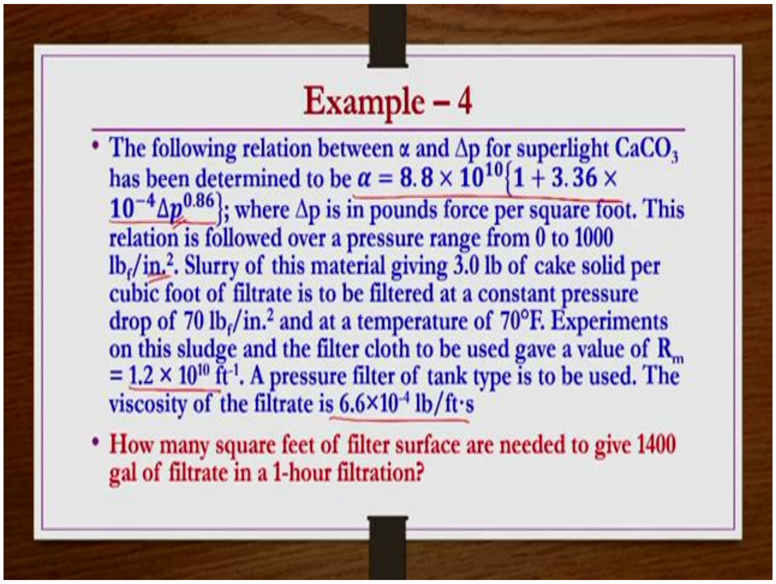

Now, we go to the another example problem, the following relation between α and Δp for superlight $CaCO_3$ has been determined to be α is equals to $8.8 \times 10^{10} \times \{1 + 3.36 \times 10^{-4} \Delta p^{0.86}\}$. So, now here cake is compressible cake, because that α as functional Δp is given, Δp is in lb_f / ft^2 so, in this equation if you wanted to get α value for a given Δp value, this Δp has to be lb_f / ft^2, that unit has to be used.

This relation is followed over a pressure range of 0 to 1000 lb_f /$inch^2$ so, but this range is given in inch squared so, you have to convert in feet square, slurry of this material giving 3 lb of cake solid per ft^3 of filtrate is to be filtered at a constant pressure drop of 70 lb_f /$inch^2$ and at a temperature of 70°F. Experiments on this sludge and the filter cloth is to be used gave a value of R_m is equal to 1.2 x 10^{10} ft^{-1}, R_m value is also given, a pressure filter of tank type is to be used.

The viscosity of the filtrate that you collect is 6.6 x 10^{-4} lb/ft s. Now, the question is how many square feet of filter surface are needed to give 1400 gallons of filtrate in an hour of filtration? So, this part of the question is a kind of measuring the filtration area.

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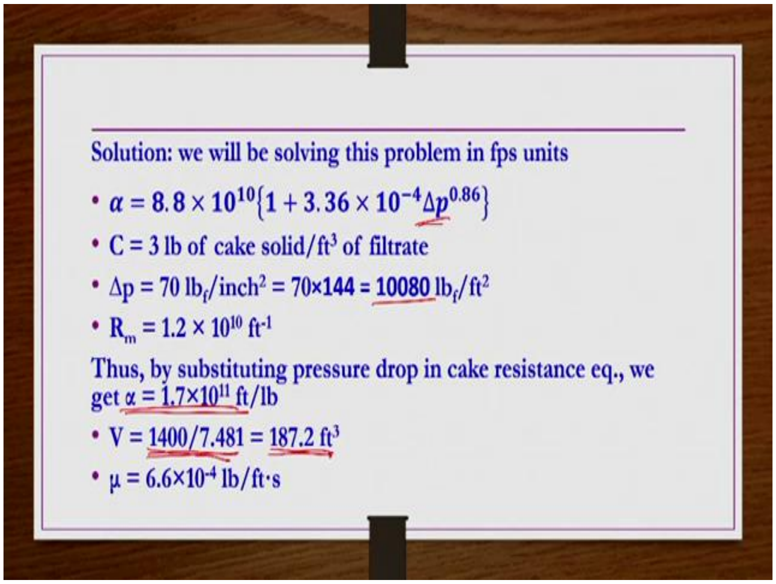

So, again we will be solving in fps units α is given this expression, C is also given 3 lbs of cake deposited on filter medium per ft^3 of filtrate that is given directly, Δp is given in lb force for inch square so, that you have to convert into the lb_f /ft^2 because here in this expression α Δp has to be lb force per feet square as per problem statement. So, Δp is 10080 lb_f /ft^2 so, that if you substitute here in this α expression you will get specific cake resistant at this pressure drop, R_m is given this value.

So, in the equation Δp when you substitute α you will get 1.7 x 10^{11} 11 ft/lb. Volume of filtrate collected is also given 1400 gallons so, if you divide it by 7.481 it will be converted into the ft^3, so, on 187.2 ft^3, viscosity is also given this value.

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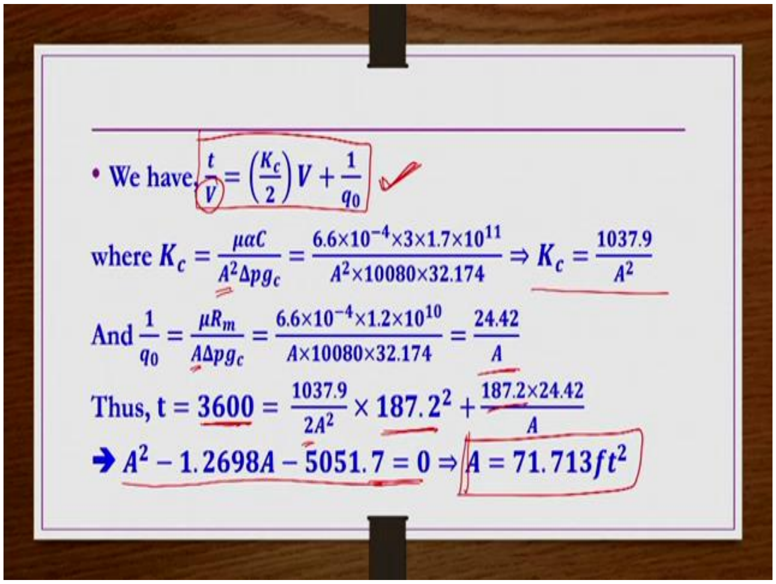

So, now, we have to use the same equation here because in this equation K_c q_0 if you write in terms of α and R_m everything so, everything is known except that A value, the area, filtration area that we can calculate here. So, before that what you do? You expand it or you straightforward find out what is K_c what is $\frac{1}{q_0}$ because everything is known, mu is given, α is given, C is given, Δp is given, g_c is 32.174. So, in K_c except A^2 everything is known, when you substitute you will get K_c is equal to $\frac{1037.9}{A^2}$.

Similarly, $\frac{1}{q_0} = \frac{\mu R_m}{A\Delta p g_c}$, here also except A everything is known, substitute all the values simplify. So, you will get $\frac{1}{q_0}$ is equal to 24.42/A. So, this K_c and $\frac{1}{q_0}$ if you substitute in this equation, then you will get the required area for this filtration which provides 1400 gallons/h. So, it is given per an hour.

So, t is given that is 60 min so, 3600s is equal to that whatever the V is there in this equation that also we are taking to the right hand side. So, K_c is nothing but 1037.9/A^2 and then 2 is as it is, and then V take to the right hand side so, V^2 so, V is also given 1400 gallons is nothing but 187.2 ft^3, so $(187.2)^2 + \frac{1}{q_0}$ is nothing but 24.42/A and then this should be multiplied by V that is 187.2. When you simplify this equation further you get this quadratic equation when you solve this equation, you get 2 roots and reliable root is 71.713 ft^2. This is the filtration area required.

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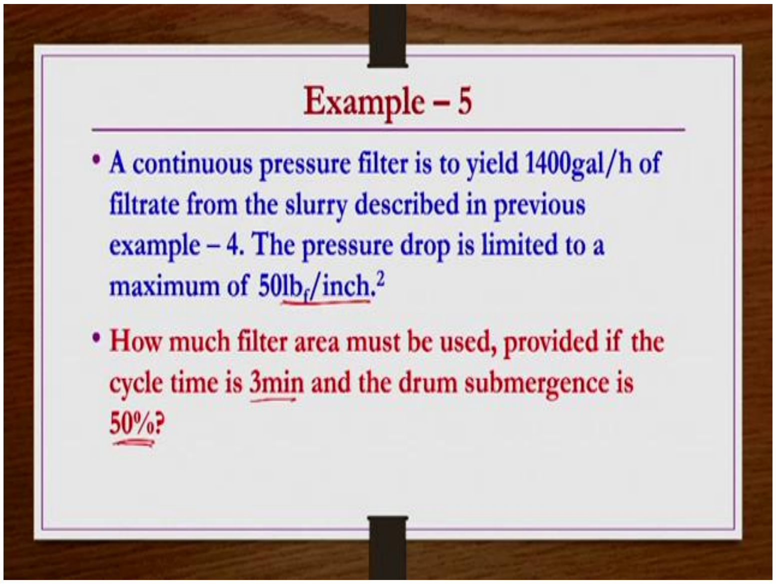

Now, we take another example problem but followed up of the example number four. So, a continuous pressure filter is to yield 1400 gallons/h of filtrate from the slurry described in previous example four. So, the properties α, R_m, viscosity everything has to be taken same as a previous example number four, the pressure drop is limited to a maximum limit of 50 lb_f / $inch^2$, in the previous problem, the pressure dropped 70 lb_f /$inch^2$ but here in this problem it is restricted up to 50 lb_f /$inch^2$.

How much filter area must be used provided if the cycle time is 3 min and drum submergence is 50 %? The previous one that we have done for kind of a batch process, constant pressure but batch process, this problem is the same slurry, same properties of cake resistance, Rm etcetera viscosity of filtrate etc. But this problem is constant pressure but continuous filtration not the batch filtration so, here we have to use the equations corresponding to the continuous filtration.

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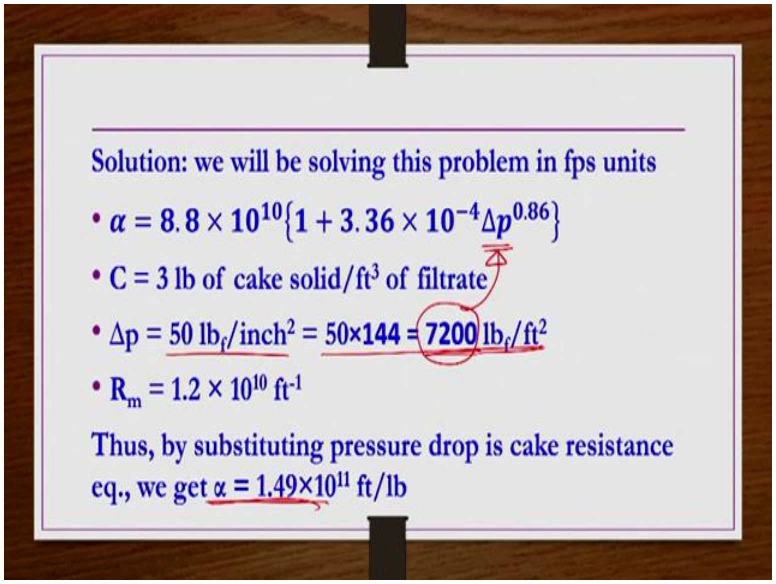

So, α is given this expression in the previous problem so, same the how to use C is also this value we given in the previous problem, Δp now, in this problem is 70 lb_f /inch^2 whereas, in the previous problem it was 70 lb_f /inch^2 now, it is in this problem it is 50 lb_f /inch^2 when you convert into lb force per feet square, because here in α definition Δp has to be lb_f /inch^2.

So, when you convert into, convert inches into ft, then do the simplification you get 7200 lb_f /ft^2 as a kind of pressure drop. R_m is given 1.2 x 10^{10} ft^{-1}. So, in this equation here now, this 7200 if you substitute here you will get α as 1.49 x 10^{11} ft/lb. So, this is the change compared to the previous problem because the pressure has changed, pressure has decreased from 70 lb_f /inch^2 to 50 lb_f /inch^2 so, α has also slightly decreased.

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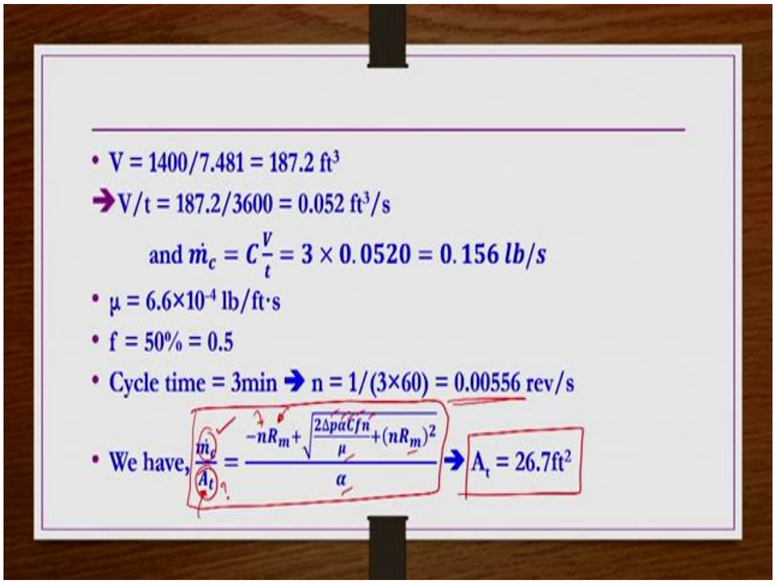

V is given as a kind of 1400 gallons and then this gallons if you convert into the ft^3 it comes out to be 187.2 ft^3 same as the previous problem. But, per hour it is given 1400 gallons/hr so, that is volumetric flow rate $\frac{V}{t}$ is given as 187.2, t is 1 hour so, that is 3600s so we have 0.052 ft^3/s and $\frac{\dot{m}}{C}$ is nothing but $\frac{V}{t} \times C$ that we know. So, C is given as 3 in the previous problem, $\frac{V}{t}$ here in this problem is 0.052.

So, $\frac{\dot{m}}{C}$ you will get 0.156 lb/s, viscosity is given and then as I mentioned in the continuous process of filtration, continuous filtration process, the area filtration is not the entire area of the filter medium but the only the fraction of area that is submerged in the slurry that area should only be taken as a kind of filtration area.

So, here 50% of the filter medium is submerged in the slurry so, f is 0.5 so, and then cycle time is given us 3 minutes so, n should be coming out as $\frac{1}{3} \times 60$ so, that is 0.00556 rps, then we have this equation for continuous constant pressure, but continuous filtration process we have this equation, in this equation now, At is known because the fraction of area that is, At is to be calculate, how much is the filtration area, this R_m is known, n we just calculated here this one, Δp is given, α is known, C is known, f is known 0.5, n is known, μ is known, everything is known in this equation, R_m and everything is known.

So, when you substitute all these things including this mc is also known, so, only thing unknown is At so, that At you will get it as when you substitute all the values and simplify you will get that value as 26.7 ft^2.

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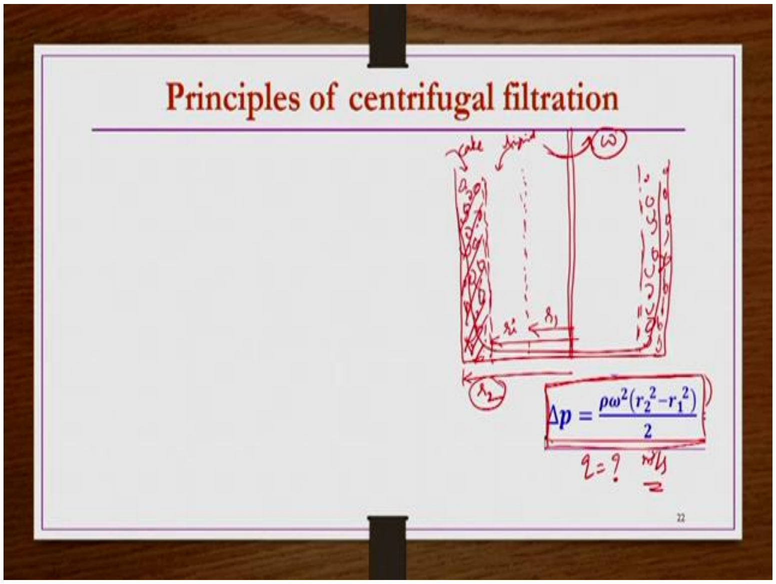

Now, we go to the case of centrifugal filtration, what happens in general centrifugation, a separation by centrifugal forces there is a kind of bowl and then this bowl is rotated with a kind of high speed or with a kind of certain speed in general, when this rotation takes place a kind of centrifugation forces will also develop, let us say initially slurry level is something like this before rotating this bowl so, when you start rotating the bowl what happens, the interface with slightly move like this, depending on the speed, if you rotate at very high speeds, so, then the interface may be like this.

So, all the material is here only so, if you rotate at very high speed, so, then there may be kind of cases like this, the most of the material or something like this here so, now, these cases, when centrifugation takes place whatever the heavier material is there that is now here in this case slurry in the slurry particles are the kind of heavier materials, particles would be gradually deposited on this surface of the bowl, like this either side, the particles would be forming a kind of cake along on this the surface, on bowl surface like this, around the bowl surface and there will be a kind of a clear liquid next to it like this.

So, here we have a kind of cake, you have a kind of liquid. So, now, this is, let us say rotating it ω speed something like that so, now, we have a kind of, we take a kind of case where, such kind of clear separation of cake and then liquid is possible as a kind of ideal case like this and do the analysis. So, what is the pressure drop under this condition? That pressure drop is related to the ω and then density of the bowl etcetera, omega and density of the liquid whatever the filtrate liquid is there that density etc that depends on that one also it depends on the inner radius of the bowl, this is r_2 and then the clear interface of the liquid whatever is there that is kind of r_1, the interface between the cake and the clear liquid is known as the r_i.

So, that means if you know the bowl radius and then if you know the thickness of the cake, you can know what is r_i, r_2- thickness of the cake if you do you will get r_i. So, Δp in general $\frac{\rho\omega^2(r_2^2 - r_1^2)}{2}$, this is any way we are going to derive in subsequent lectures for the time being we will be taking like this, this is what happens in centrifugal filtration.

So, whatever the rotational speed is there that can be related to the Δp so, under such conditions what is q? This is a kind of continuous process, continuously cake is being taken out, continuously liquid is taken out, so, what is the volumetric flow rate in meter cube per second that you can principles that you can develop here or you can develop the equation those we can use for calculation for a given system.

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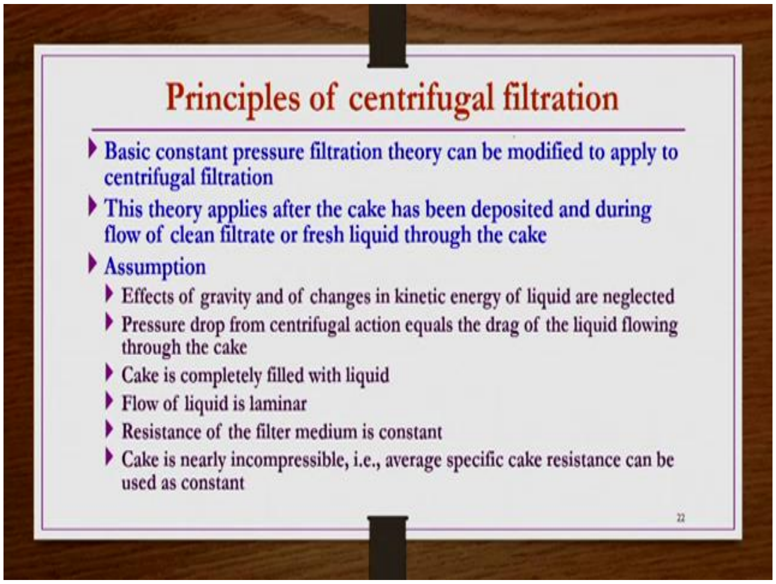

So, basic constant pressure filtration theory whatever is there that can be modified to apply centrifugal filtration here as well. So, this theory applies after the cake has been deposited and during the flow of clean filtrate or fresh liquid through the cake, it is a kind of continuous process, when there is a whatever the equation that we are going to develop so, it is valid for the case where already there is a certain amount of cake is already deposited and then the clear filtrate or fresh liquid is passing through the cake.

So, there are several assumptions here because, so, many things are happening in centrifugal filtrations so, what are those assumptions? Effects of gravity and of changes in kinetic energy of liquid are neglected, compared to the centrifugal forces these quantities gravitational force and then kinetic energy are very small, that is what it mean by and then pressure drop from centrifugal action equals the drag of the liquid flowing through the cake, same as the kind of packed bed case, cake is completely filled with liquid.

So, interstitial space between the particles within the cake are not free, they are already occupied by, always occupied by liquid and then flow of liquid is laminar and then resistance of the filter medium is constant it is not changing, cake is nearly incompressible, that is average specific cake resistance should be used as a kind of constant value, these are the some assumptions.

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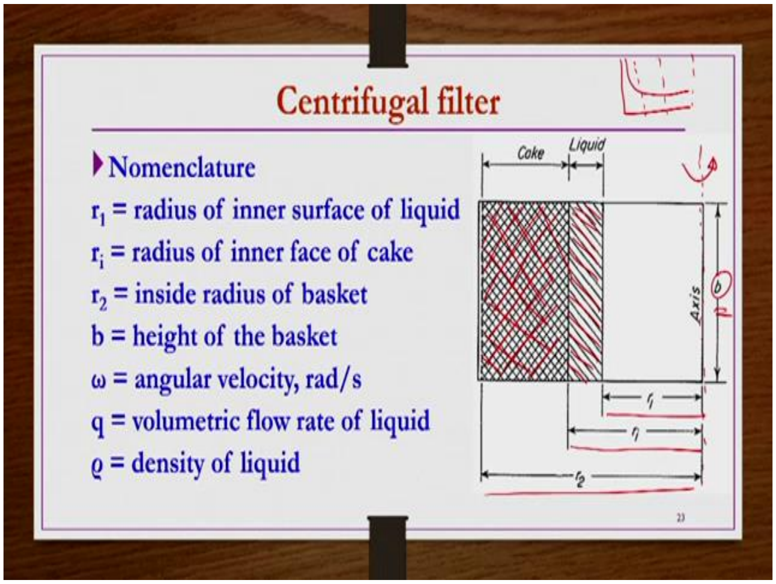

Then centrifugal filters. So, let us say this is the axis of the bowl, the only one side we are drawing it the same side, the same is other side also under the idealized conditions when the cake is the solid particles are depositing along the bowl surface, inner surface of the bowl as a kind of cake, they are deposited all the particles are deposited along the inner surface of the bowl and then they are forming kind of cake and then there is a clear liquid adjacent to it.

So, this interfaces are not state once like drawn here in general we may be having a kind of interfaces something like this, however we take for this is for the cake and this let us say for the liquid so, we take this is a kind of almost a kind of state something like this, for simplification we take this interface of liquid as well as the cake that has formed is having a kind of a uniform thickness along the vertical dimension of the bowl, that is along the b at the bottom, whatever the thickness is there, the same thickness is there at the top which is in general not true.

So, for further nomenclature we can take here. So r_1 is the radius of inner surface of the liquid and then r_i is the radius of inner surface of the cake and then r_2 is the inner or the inside radius of basket and then b is nothing but the height of the basket and then ω is the angular velocity in radiance per second at which the bowl is rotating. And then q is the volumetric flow rate of liquid that is being continuously taken out, rho is the density of the liquid.

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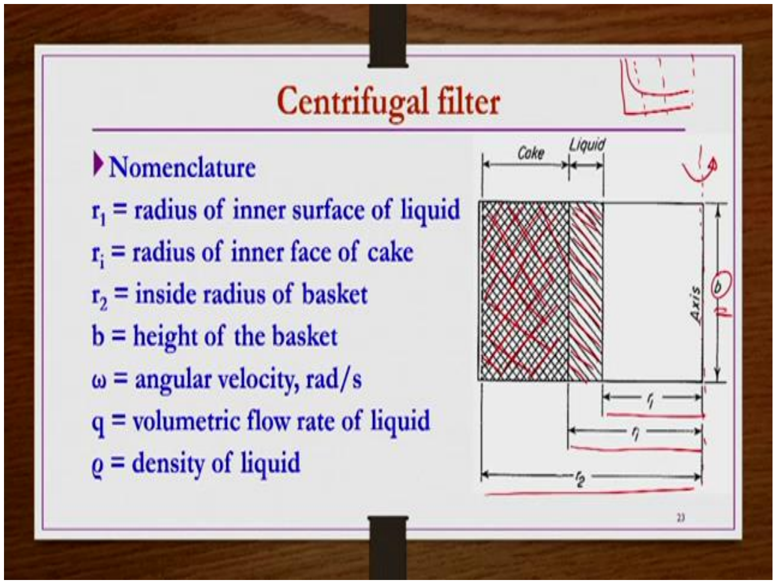

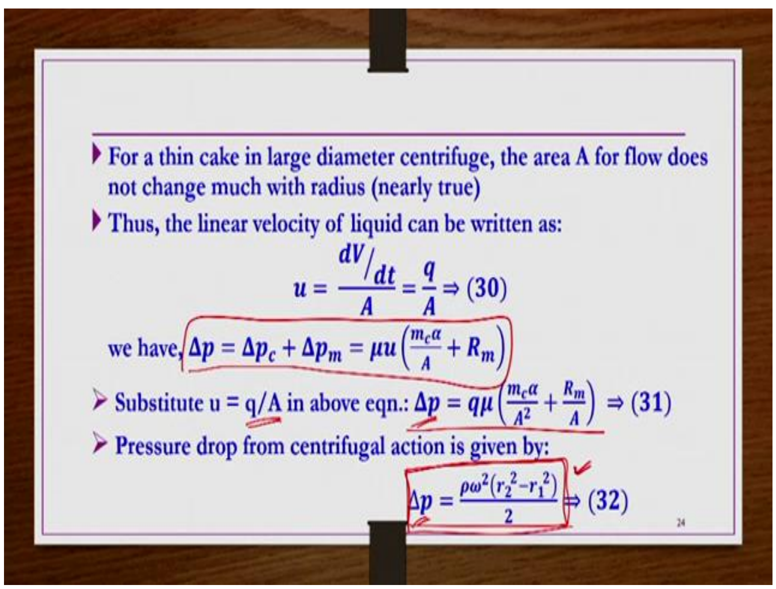

So, now whatever the constant pressure filtration equations are there they can be same can be used here with a kind of a few modifications, what are those few modification? We are going to see now, for a think cake in large diameter centrifuge the area A for flow does not change much with radius, nearly true because if the bowl that if you take here if this area the cake is very thinner, the cake is very thinner than this area is going to be very large, A is going to be very large.

So, because of that one this area for flow does not change much with radius of the cake that has been formed because the cake is a kind of thin cake now, thus, the linear velocity of liquid can be written as u is equals to $dV/_{dt}$ by A so, $dV/_{dt}$ we can write it as $q/_A$ and now, we have this equation number 6 developed in the previous lecture, Δp is equal to $\Delta p_c + \Delta p_m = \frac{\mu u m_c \alpha}{A} + R_m$ now, in this equation substitute u is equals to $q/_A$ then you have this equation.

So, but under the centrifugal force, what is the pressure drop here? The pressure drop is as I mentioned $\frac{\rho\omega^2(r_2^2 - r_1^2)}{2}$, this we are going to derive when we discuss the centrifugal separation process in later part of the course, for the time being let us take this equation as it is.

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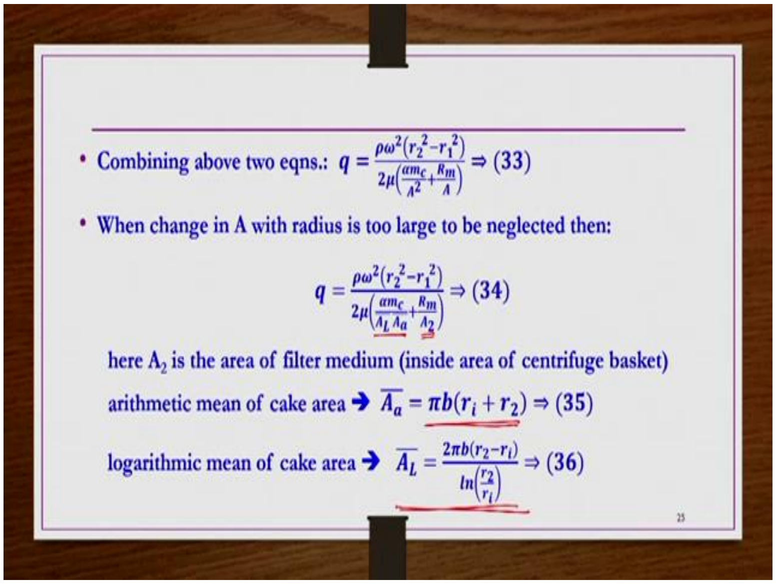

So, now this Δp in equation 31 and this Δp in equation 32 if we equate. Then you get an expression for q that is $q = \frac{\rho\omega^2(r_2^2 - r_1^2)}{2\mu\left(\frac{\alpha m_c}{A_L A_\alpha} + \frac{R_m}{A_2}\right)}$. Now, when change in A with radius is too large to be neglected, then this A^2 is written $\overline{A_L}$ and then $\overline{A_a}$ to match better with experimental observations in general, where A_2 is the area of the filter medium inside area of the centrifugal basket that is whatever the $2\pi b r_2$ is there that is A2 here, because, this you know filter medium resistance this A_2 is nothing but area filter medium that is inside area centrifugal, centrifuge basket that is $2\pi b r_2$

And then $\overline{A_a}$ is nothing but arithmetic mean of cake area that is $\pi b(r_i + r_2)$because cake is between r_i and r_2 only, only that part is the cake. So, $\pi b(r_i + r_2)$ would be giving the arithmetic mean of cake area, it is arithmetic means similarly logarithmic mean of cake area can be taken as $\overline{A_L} = \frac{2\pi b(r_2 - r_i)}{\ln\left(\frac{r_2}{r_i}\right)}$.

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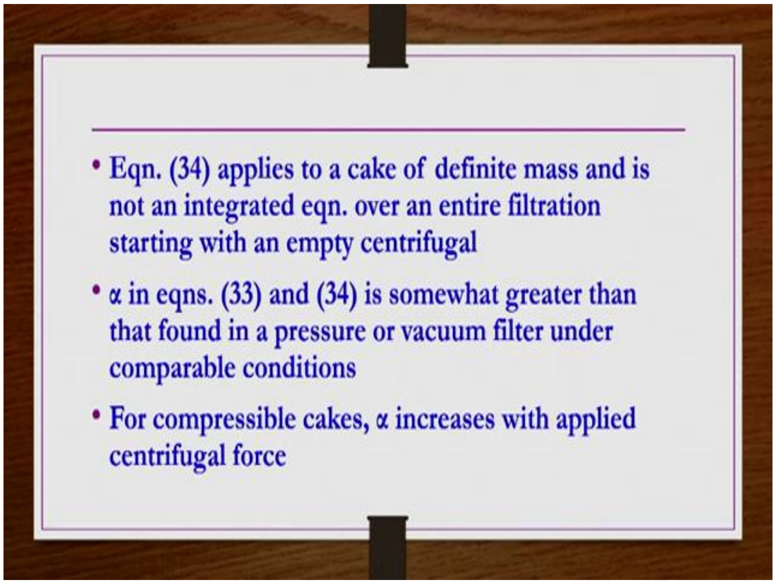

So, this equation 34 whatever develop in terms of $\overline{A_L}$, $\overline{A_a}$ and A_2 applies to a cake of definite mass and is not an integrated equation over the entire filtration starting with an empty centrifugal, it is not like as I mentioned at the beginning of the principles of centrifugal filtration process what we have taken these equations are valid for the case were already cake has been deposited on the bowl surface and then liquid is continuously flowing through and then being separated as a kind of fresh liquid as of clear filtrate.

So, this is for the such conditions it is valid, but it is not a kind of overall integrated equations kind of thing as we have seen in the pressure filtration processes, α in this equations is somewhat greater than that we found in a pressure or vacuum filter under comparable conditions, for compressible cakes α increases with applied centrifugal force. However, in this theory whatever the equation that we developed there we applied, we assume that α is independent of Δp and then a average Δp should be taken as a kind of constant value for that α, though, it increases with increase in the centrifugal forces.

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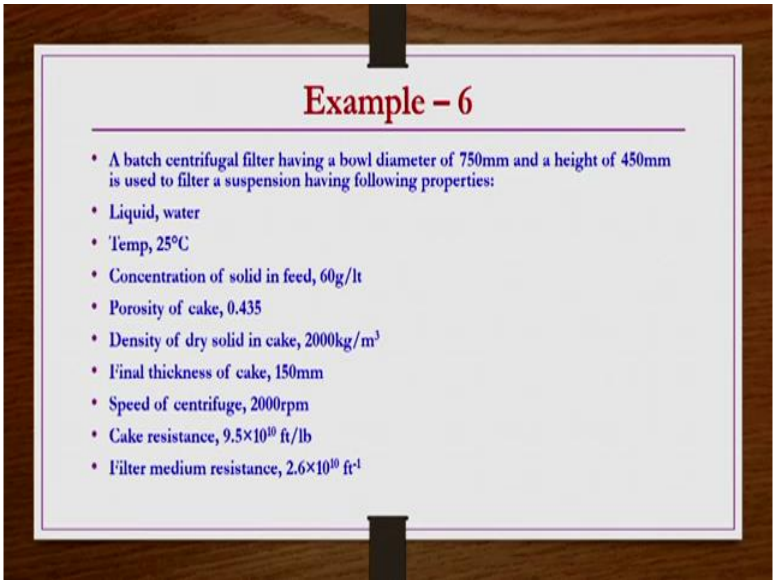

So, now we take an example problem based on the centrifugal filtration process, here batch centrifugal filter having a bowl diameter of 750 mm that is r_2 by, that is to 750 mm and height b is 450 mm is used to filter a suspension having following properties. So, it is a liquid water at temperature 25°C has been used, concentration of solid in feed is 60 g/L, porosity of cake is 0.435, density of dry solid in cake is 200 kg/m^3, final thickness of cake is 150 mm, speed of centrifuge is 2000 rpm, cake resistance α is 9.5 to 10^{10} ft/lb and then filter medium resistance R_m is 2.6 x 10^{10} ft^{-1}.

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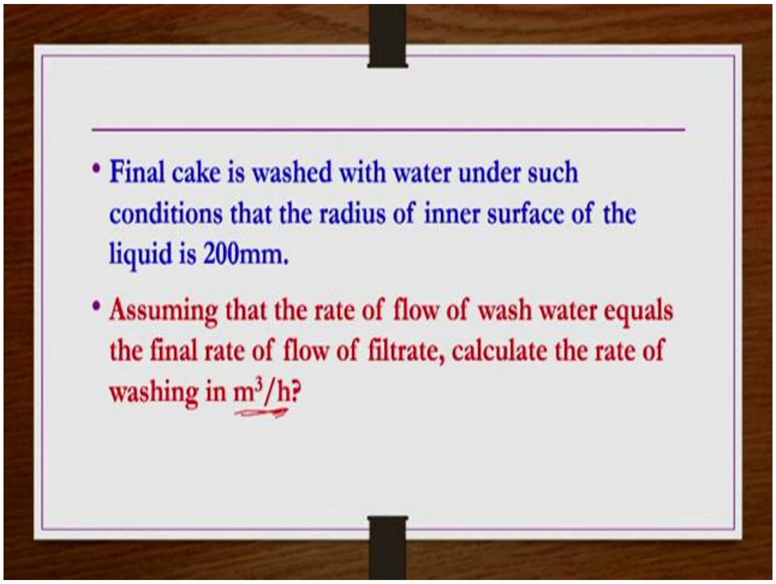

Then final cake is washed to get water under such condition that the radius of inner surface of the liquid is 200 mm. So, that is r_1 is 200 mm that is also given, then assuming that the rate of flow of wash water equals the final rate of flow of filtrate, calculate the rate of washing in meter cube per hour. So, that means straight forward that filtration and then washing occurring in the same way, exactly the same way so, whatever the filtrate volumetric flow rate q that you find out the same thing would be the wash liquid volumetric flow rate in meter cube per time so, it is required in per hour so, you get the meter per second that you have to convert into the m^3 /h.

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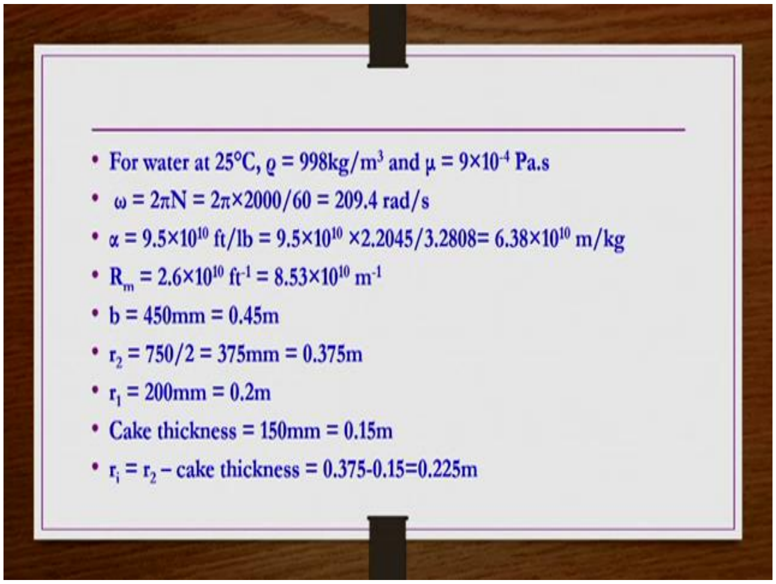

So, for water at 25^{o}C ρ and μ we can find these values from any standard textbooks, omega is required but n is given so, 2000 rpm is given so, $\frac{2\pi}{60}$ if you do that will get omega in radiance per second. α is given in ft/lb so, that you have to convert in mass/kg.

Similarly, R_m is given in foot inverse, if you have to convert in meter inverse units, b is given 450 mm that is 0.45 m, r_2 is given 750/ 2 that is 375 mm or 0.375 m, r_1 that is, inner surface of the liquid radius is 200 mm that is given so, that is 0.2 m is r_1, cake thickness is given as 150 mm so, that is 0.15 mm. So, r_i you can calculate by subtracting this cake thickness from r_2 so, r_i is equals to r_2-cake thickness, this $0.375 - 0.15 = 0.225m$.

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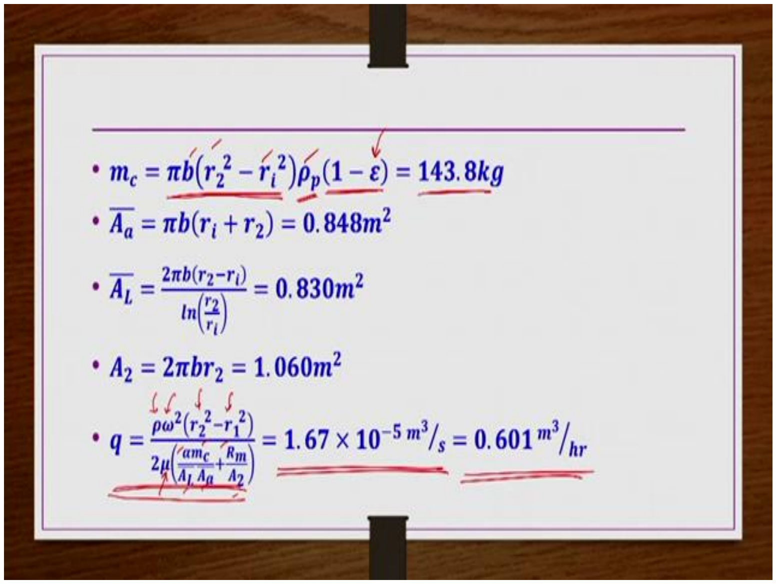

So, now everything is known here except the mc, mc is nothing but let us say the volume of the cake that you have to find out then you multiply by the density of the particles, then you could get it. So, cake is like between r_2 and then r_i, r_2 and r_i that distance only cake is there. So, within that only solid particles are there so, $\pi b(r_2^2 - r_i^2)\rho_p(1-\varepsilon)$, if you do, you will get volume of the particles within the cake, within the cake, because, the entire cake is not full of particles and there are interstitial spaces filled with the liquid.

So, that interstitial space is $1-\varepsilon$ is the fraction of the particles. So, $\pi b(r_2^2 - r_i^2)(1-\varepsilon)$ if you do, you will get the volume of particles within the cake and then if you multiply that one by the density of the particles you will get the mass of the particles within the cake that you get 143.8 kg because here everything is known, everything is known in this equation.

So, you substitute all these numbers you will get 143.8 kg, then $\overline{A_a}$ is nothing but $\pi b(r_i + r_2)$arithmetic mean of cake area so, that you can calculate here similarly, logarithmic mean of cake area also you can calculate by this $\frac{2\pi b(r_2 - r_i)}{\ln\left(\frac{r_2}{r_i}\right)}$so, you will get 0.83 m^2 and then A_2 is the filter medium, that bowl area that is $2\pi b r_2$ so, that comes out to be 1.06 m^2.

So, everything is known now, in this equation of q, in this equation of q everything is known, rho is given, water we got the properties, ω we got, r_2, r_1 is known, μ is known, α is known, R_m is known, m_c we calculated, $\overline{A_L}$ $\overline{A_a}$ A_2 already calculated, you substitute all these numbers here. So, then you will get q as 1.67 x 10^{-5} m^3 /s, that if you wanted to make it a kind of hours.

So, what you have to do, you have to multiply it by 3600 when you do it, you will get 0.601 m^3 /h, this is how we can solve the problems related to the cake filtration. So, what we have done in this class we have solved several problems based on the cake filtration by pressure filtration and then we also discussed the principles of centrifugal filtration and under such conditions, we have also taken an example problem.

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The reference for this lecture is primarily, the entire lecture has been prepared from this first reference book Unit Operations of Chemical Engineering be McCabe Smith and Harriot. However, there are other reference books that we have in this course in which you can find some information about the Principles of cake filtration processes. Thank you