

Fundamentals Of Particle And Fluid Solid Processing
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Lecture - 30
Sedimentation (contd.)

Hello everyone, welcome back to the another class of Fundamentals of Particle and Fluid Solid Processing. Till last class, we have seen the fundamentals of Sedimentation, its different mode during this process that is the batch settling and the continuous operation. We will continue with this idea that we ended in the last class that the concept that in continuous operation, how this concentrations at any axial position from a vertical distance from the top or from the bottom that can be measured.

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Thickener

- produce a clarified liquid
- liquid upward velocity < particle settling velocity
- diameter of the tank
- create thickening of the suspension
- particle residence time
- depth below the feed inlet

So, we started with this concept of this thickener that equipment that is used for sedimentation. Now, we have seen its working principal. And the reason that earlier we have studied that what why there was derivation for expression of flux for net upward as well as the downward flow ok. So, because in thickener, we can have two zone basically. So, in practice we have this of flow condition where the clarified liquid are flowing and is taken out from the vessel called the overflow. And the downward motion of the solid particles or the down flow region where the solid particles settles.

There is a stirrer that moves and the utility of this stirrer we have seen earlier or we have discussed earlier that it actually reduces the apparent viscosity of the suspension. It moves at a very slow pace and what happens it actually scrapes these sedimented materials that falls on this bottom of the surface. It collects, it helps to collect those sedimented particles which are taken out from the vessel at certain point of time or can be regularly or continuously. And the thickened, this thickened liquid the whole thing that basically goes out from the bottom of the liquid this vessel as the thickened liquid outlet or we call the underflow.

So, and another vital thing that this feed that comes here is not just left at the top surface of this vessel or the pool of liquid ok, it actually comes down a bit that is a certain depth from the top surface of the vessel. And it is introduced in a possibly less turbulent manner. Now, as I mentioned that this thickener has two fold objectives; one is to produce the clarified liquid the overflow as clear liquid as possible and the other is creating thickening suspension of the suspension.

Now, to produce this clarified liquid, we typically focus we have to focus on the diameter of the vessel, because at this section the liquid upward velocity has to be lesser than the particle settling velocity. The design parameter of this diameter has to be such that this liquid upward velocity should be lesser than the particle settling velocity for the corresponding feed or the feed rate that we are introducing. So, which means the diameter of the tank is of considerable importance or considerable consideration in this case.

Now, for the down flow region, to create the thickening of the suspension, that means, which depends on the particle residence time the depth below the feed inlet is what that is important; because from here the feed is given or provided and then the particles travels this distance. In ideal case, when all the particles settles, you have a clear liquid zone that we have discussed earlier and that liquid is withdrawn from the overflow. So, since in a real thickener, we have this two zones, that is one is the up flow zone and other is the down flow. The up flow that is above the point is this above this feed inlet or the feed well and the other region is below this feed nozzle or the feed well.

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Thickener

- material balances over the thickener are:
 - total: $F = V + L$
 - particle: $F C_F = V C_V + L C_L$
- link the total continuous flux plots for the upflow and downflow sections in the thickener

So, if we consider that the feed rate is at F the volumetric feed rate, the corresponding concentration of the feed is of C_F which is introduced at this point at a certain depth from the top of the vessel, then say we have the overflow volumetric flow rate of V and the underflow we have L , the corresponding concentration is C_L and C_V like here we have C_F ok.

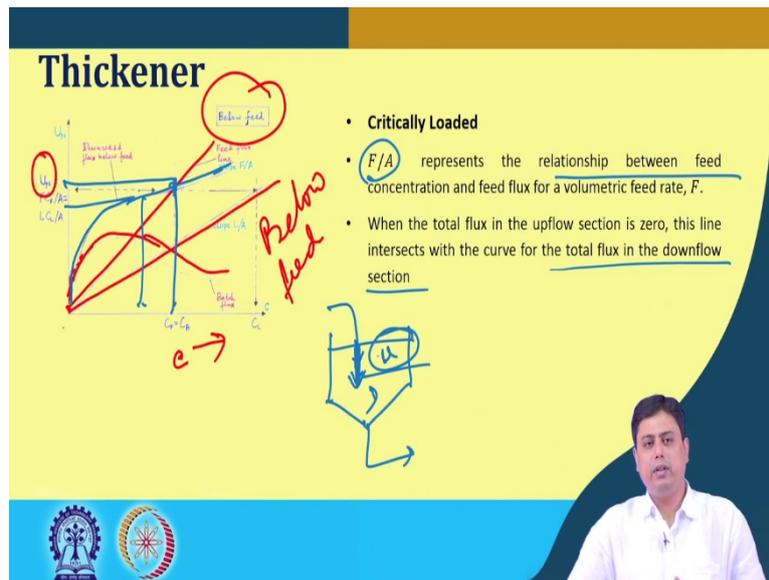
Now, as I mentioned that there is basically two zones in a real thickener; one exactly below the feed nozzle or the feed well, say they it has a mean particle concentration of C_B . And on the up flow zone, say we have the mean particle concentration of C_T . For the sake of understanding, you can remember the T here is for the top portion, B for the bottom portion ok. C_V is for the overflow; C_L for the underflow. Now, the material balance over the thickener for overall material balance as well as the particle balance, we can have these two expressions that is

$$\text{total: } F = V + L$$

$$\text{particle: } F C_F = V C_V + L C_L$$

So, these two expressions ok, these two expressions actually now can be linked with this total continuous flux plots for the up flow and down flow sections in the thickener. So, this if we go into details, we will see that these two expressions, combines this total flux plot for the up flow and the down flow sections in the thickener.

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Now, how that happens say we have this is the below feed section which is of immediate important. The particles are settling in that zone. So, this is the say below feed. Now, this is the say this we have say this is the batch flux data. This is the concentration in the x direction and y direction we have the volumetric flux ok. Now, which means this F/A , V/A and L/A ok, these slopes these are the value of slopes of the bulk flow rate of the underflow and the overflow.

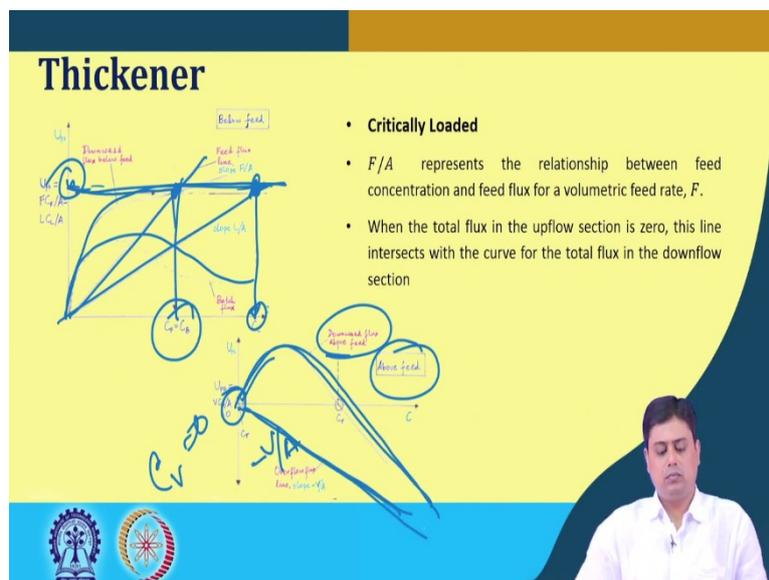
So, in this case, so this line say is having a slope of L/A with the underflow ok. And this is the F/A slope starting from this 0,0 point. And then like we have seen earlier that the settling rate that the batch settling flux plus the bulk gives us the downward flux of the this suspension below the feed which say the resultant is this one. Now, this F/A physically what it means, it represents the relationship between the feed concentration and the feed flux for the volumetric feed rate F . When the total flux in the up flow section is 0, again you remember the thickener geometry.

So, if feed is fed at a depth of this distance, you have up flow in this zone and you have down flow in this zone. So, when the total flux in the up flow section is 0, then this is F/A , this line with this slope intersect this total curve, total flux curve ok, this intersect with the curve for total flux in the down flow region, which means this point intersection is basically tells us that this is a critical value.

Where if you operate that the thickener with this concentration and this flux rate there would be no upward or say the flow net total flux in the up flow section. In this section, there would be no flux in the up flow section, which means this is a critical value beyond which or above which the thickener will be overloaded. There will be the particles that would flow in the upward section as well. Or if it operates of value below this one, then it would operate in underflow condition or let say under loaded condition, all the flux will be in the down flow section.

So, let me read it once again for a real thickener, once we have this batch settling data and the bulk flow rate what we can do, we can draw this F/L which is the feed flow rate by A , sorry, the area of cross section, so F/A and L/A as well as well as the V/A . Now, the V/A is happening as a up flow, upward flow. So, in this case, as we are considering these are having the positive slope that would have in the negative direction which would be looking like this kind of a scenario.

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That and the below this, this is the above feed scenario ok. So, the downward flux above the feed would be something like this, because here we have the over flow flux that is having a line with the slope $-V/A$, because the overflow flow rate is V . So, here the overflow flux line will have a slope of $-V/A$ ok and it would not cross anywhere in this of this total flux above the feed, which is the downward flux above the feed, this line is a downward flux

above the feed. So, this is the batch flux data. We have the F/A and L/A line. This is the resultant total flux that is downward below the feed.

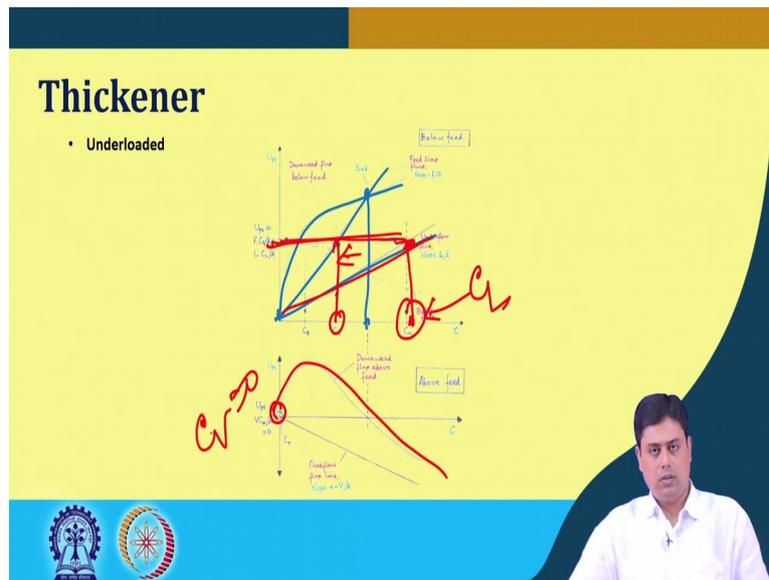
The point where this intersects the point indicates that there is no up flow, which means that is a critical point at which or the critical condition at which the thickener can operate. So, if we say that this is a critically loaded thickener and at that position this C_F or the feed concentration is actually the overall bottom mean composition which is C_B . Now, the point as I mentioned that it intersects the y axis at a value U_{ps} which is the critical flux, at that critical flux if we extrapolate this line, it intersects this L/A curve at a point. And that point indicates that what would be our underflow concentration.

So, for critically loaded thickness, thickeners, when we have this concentration we know from the intersection between the F/A slope line and the total flux line, from there we can have this critical flux. This critical flux line, where it intersects with the L/A slope line that concentration is the concentration of the underflow. And the overflow condition that means, now since this is the critically loaded scenario that means, all the flow is happening or all the particle settling is in the downward motion or in the down flow zone, there is no particle in the up flow or up flow region and that is why C_V is basically 0. There is no other solution for C_V from this graph.

So, I hope you have got this point because this is the critically loaded scenario; the critical point where the thickener is working. Now, critical means there is no flux or no particle flux in the up flow section total flux in the up flow section is 0. At that point, this line of F/A intersects, this total curve at a certain point that is our critical condition or the critical concentration of the feed and the corresponding flux is the critical flux.

At that critical flux the line, where it intersects the straight line with the slope of L/A that gives us the concentration of the underflow. And this is the line having a slope of $-V/A$ which is above the feed which is the up flow region. Here we find the solution for C_V is only one possibility that is C_V is equals to 0.

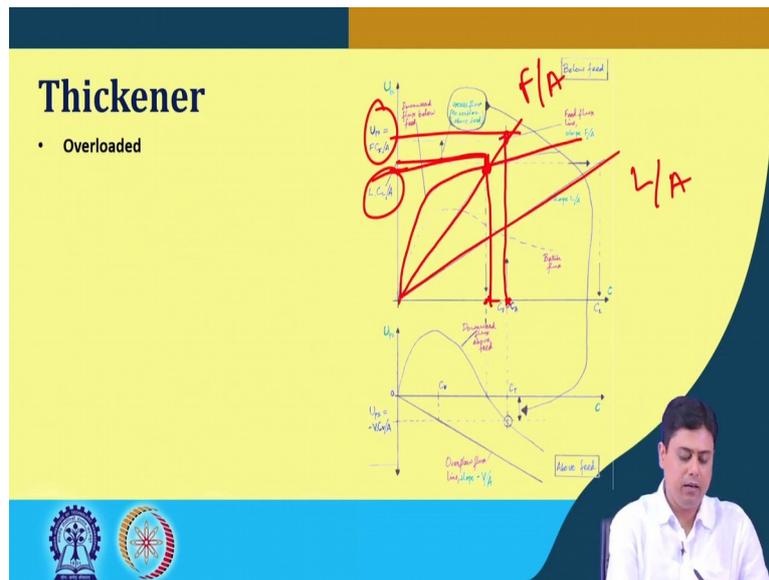
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So, which means that in under loaded condition or the under loaded condition what would happen. So, this is our downward flux below the feed ok. This is F/A line, this is L/A line. This is actually the critical point. But say our thickener is operating with the $C F$ this value, which means it is operating below the critical region or the critical limit, which is that means, their definitely would not be any net flow in the up flow region total flux in the up flow region is 0.

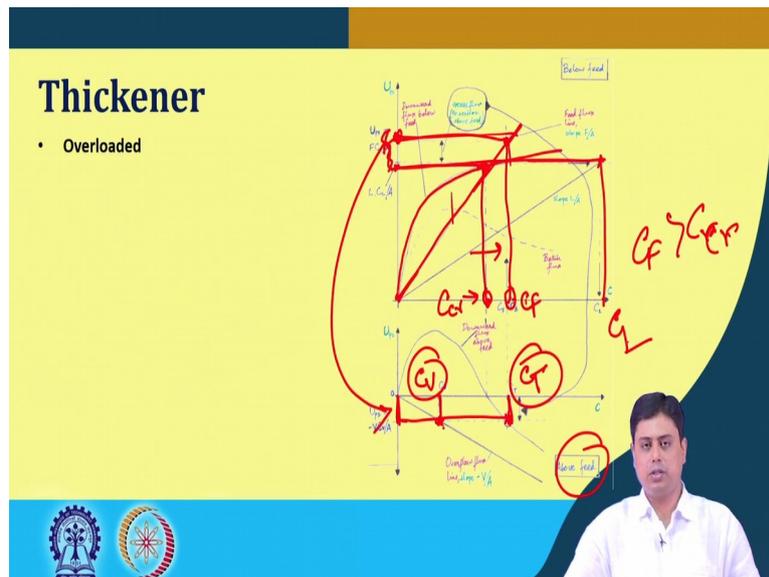
So, the corresponding concentration at the down flow or the underflow would be the intersection between this line and line with the slope of L/A . This would be our C_L . And all the flow is happening in the down flow region. This can also be seen from here that the only possibility of this solution for C_v is the 0. So, in under loaded condition, everything is happening in the down flow region.

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So, what happens when this is overloaded condition? Say the overloaded condition, by this we mean that again if we draw those curves that this is the downward flux below the feed total flux, this is a line with slope L/A , this is our the line with slope F/A which means our critical point is this one. But say the thickener is operating with a C_F that is in excess of that which means the scenario is overloaded. Now, what happens, once this is overloaded we can see that actually for that condition, the bulk flow rate is basically this one, which is the U_{ps} corresponding to this line. But critically it can handle this value, which is LC_L/L that is the maximum possibility it can handle, clear.

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Which means the intersection of this critical line this F/A line and the total flux gives the critical point. But we see that the thickener is working with the concentration at the feed in excess of that, in excess of this C_F , this critical say if I say C_{cr} if this is the concentration C critical, then say this is the C_F it is operating which is in excess of that. So, this C_F , actually correspond because F/A line represents the relation between the flux and its corresponding concentration.

So, if the concentration is this one that means, the feed flux is this one this value. But the thickener can handle this critical condition; critical condition means again the condition where the total flux in the upward section is 0. Now, it is overshooting that value which means now there will be some excess flow which will go in the upward section, because in underflow condition there will not be any flow in the upward section or the up flow section. But in overloaded case, this would be the excess flow rate that it can handle in critical condition. Which this value if we plot for the above feed scenario, it would again cross this $L - V/A$ line at a certain value and the total flux at a certain concentration.

Now, the point where it intersects this total curve total flux, this concentration is the C_T which is the mean concentration at the top section ok. And the line it intersect with the V/A line, the point where it intersect this one this is C_V which is the concentration in the overflow ok. So, this is the concentration in the overflow, this is the concentration or the mean concentration in the top section. And here similarly like the previous one in the line

corresponding to the critical flux that it intersect with this L/A line, that is the concentration of C_L that is the underflow concentration. So, which means we can have all that necessary concentration values if we can have this plot or such information.

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Problem

Using the batch flux plot data given in the following Table, graphically determine the limiting feed concentration for a thickener of area 300 m^2 handling a feed rate of $0.03 \text{ m}^3/\text{s}$ and with an underflow rate of $0.015 \text{ m}^3/\text{s}$.

- Determine the underflow concentration and overflow concentration under these conditions.
- Under the same flow conditions as above, the concentration in the feed increases 110% of the limiting value. Estimate the solids concentration in the overflow, in the section of the thickener above the feed well and in the section below the feed well.

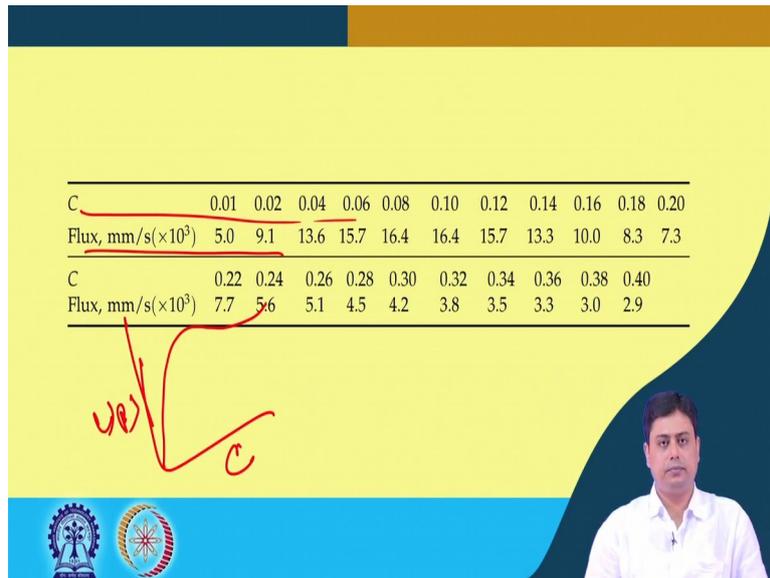
Handwritten notes on the slide:

- $V = F - L$
- Diagram of a thickener with a feed well.
- $F = \frac{F}{A}$
- $L = \frac{L}{A}$
- $-\frac{V}{A}$

So, how this information are useful? Say we have a problem that using the batch flux plot given in the following table in the next slide I have that table. Graphically determine the limiting feed concentration of a thickener that has a cross sectional area of 300 m^2 handling a feed rate $0.03 \text{ m}^3/\text{s}$ with an underflow rate of $0.015 \text{ m}^3/\text{s}$. So, which means for a thickener area cross sectional area is given, feed rate is given ok, underflow rate is given.

We have to determine the underflow concentration and overflow concentration under this condition. This is the first part. So, how should we solve this? First of all this is F , this value is known. So, we can easily calculate what is V , which is $F - L$ ok? And then we can find out what are the values of F/A , L/A and V/A or rather $-V/A$. Then what would happen we have this data given.

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That is the C; this is the flux. So, C and this the flux U_{ps} is mentioned. If we plot this say we have a plot like this ok. So, this is for the batch settling curve, like this one that we had here.

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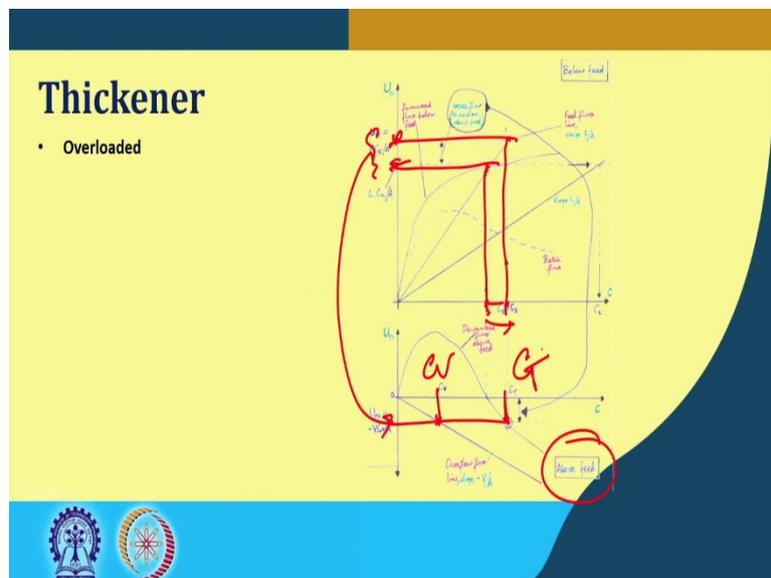
Say we have got a plot like this. Then what we do we have to draw this L/A and F/A line, this is the L/A and this is the sorry this is the F/A and this the L/A line or the these are basically the slope F/A line means the slope having F/A and the slope having L/A value. Once we have that the point where sorry after that what we do we add this batch flux data with this L/A data, because the total flux at any point is basically the settings flux plus this

underflow concentration or the underflow flux. By doing that, we get this curve this is a total flux plot.

Once we have it then we will see that the point of intersection of F/A line and this total flux that is the critical concentration, the point the x axis corresponding to that intersection point is our critical point or the critical concentration that the thickener can operate, beyond which there will be total flux or the flux in the up flow zone. The line the straight line that corresponds to the stored critical flux and where it intersects with this L/A line will give us the concentration of C_L or the concentration at the bottom of this and underflow condition.

And similarly here we can have since we can then see whether that concentration is basically beyond or below the critical limit. If it is below critical limit, then the concentration of V or the overflow would definitely be 0. The second part asks that under same flow condition if the concentration of feed increases 110 % of the limiting value which means we are overloading that in that case what would be the solid concentration in the thickener overflow as well as in the underflow. So, again in this case, once we have that then see this scenario becomes much easier.

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So, once we have found out say this is the critical point and our current operating point is 110 % extra than the critical limit, we draw this line once again and we find out what is the actual flux, what is the difference between the actual flux and the critical flux, and that one is added at the bottom of this or say about the feed this flux condition and we find out the

corresponding V , C_v and the mean concentration at the top region. So, this is how we use this information or if the problem is given in such a way, this graph or this information these graphs are helpful in calculating those concentrations.

So, for any thickener problem, I hope you should be able to find out that what are the concentrations, below the feed depth above, the feed depth at its critical operating concentration provided the sufficient information are given like the batch setting data, the flow rate, the concentration of the flow rate the feed rate ok. So, with this we will come to end of this section that is the separation of solids from fluid by means of sedimentation. In the next class, we will be coming up with the another section. And until then I thank you for your attention and listening to this.