Fundamentals Of Particle And Fluid Solid Processing
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Lecture – 27
Sedimentation (Contd.)

Hello everyone. Welcome back to the another class of Fundamentals of Particle and Fluid Solid Processing. Today we will continue with our discussion that we started in the last class that is the separation of solids from fluids by the mean of Sedimentation.

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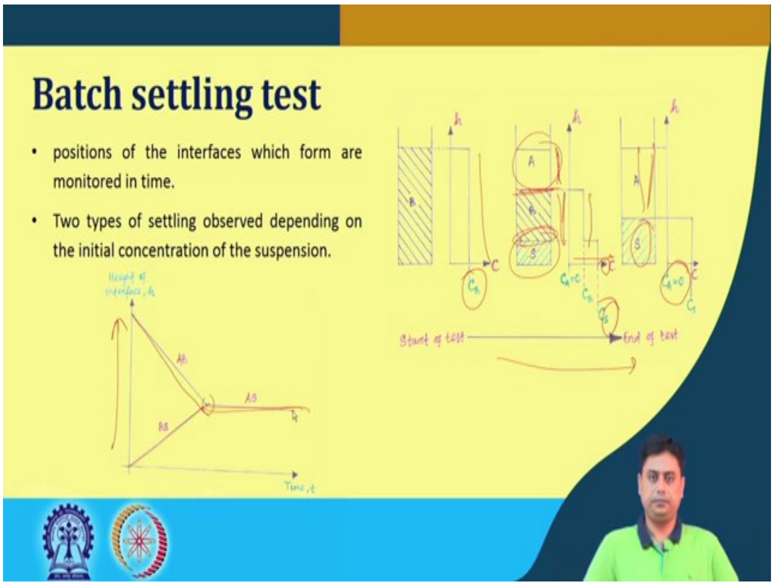

Now, we have discussed this simple batch settling test where we assume that, if we can identify the positions of interfaces of which form regularly monitored. Now, if we observe this clear fluid interface of clear fluid and the suspension interface at a regular time then we will see two types of settling phenomena. One is that is described here on this slide is that let us say you have somehow created a suspension of initial concentration certain C_B which is mentioned here. Now, it is filled till a height h from the bottom of the vessel and then you leave it for this suspension to settle.

What you would observe that after a brief period of time, when the acceleration is completed of this particles there will be a steady rate of this clear liquid or the clear fluid and rest of the suspension there is a interface. And, you would also observe that at the bottom some particles have settled that is the sedimentation. And, in between you will have a portion where the concentration of the particles are nearly equal is nearly equal to that what you prepared the suspension initially. And, then if you still continue with this experiment after a brief period of time, you would see that there is clear two layers.

One is that sedimented portion, the other on top of that we have a clear portion of the liquid or the fluid. Now, this C_A C_B these are the concentrations that are mentioned. So, throughout this height we have a concentration C_B. Here this is the height h, this is the concentration coordinate ok. So, we would see that for this portion the concentration C_A is basically 0. Then for this height the intermediate height or the transient state, where the concentration of the suspension is that of the similar to what we have started with that concentration again more or less uniform with respect to position and then you have the sedimented concentration here that is the C_s.

If you keep it for a longer time at the end of the experiment you would have the concentration in the zone A as 0 solids concentration and, here you have a certain concentration of the sediment that is the final sedimentation concentration. This is if we say; let us say this is the Type 1 of the settling phenomena in a batch settling test. And, then if we look at the interface height versus time data that would look like something like this, that if this is the interface height the AB interface that is the clear liquid and the suspension will steadily decrease. The suspension interface between B and C will steadily increase and at a critical point it would be stable after a critical time or a certain time. And, there you would have the interface of A and S which is stable.

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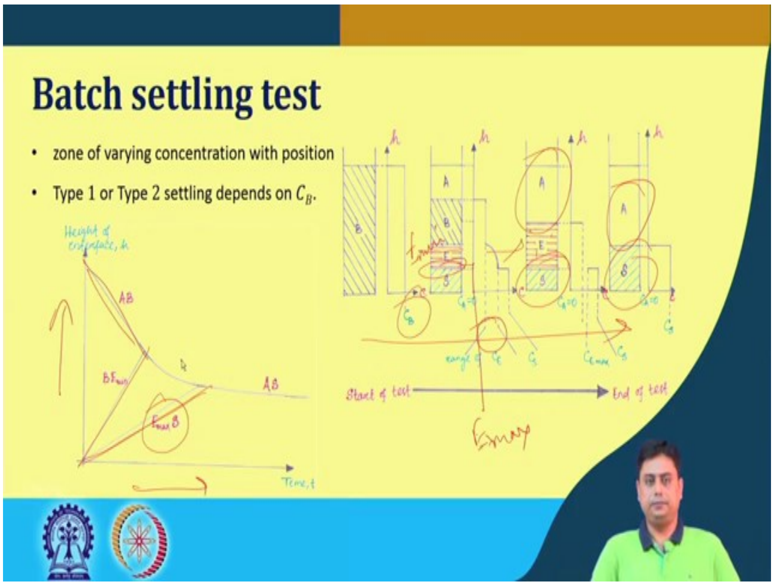

In other type of settling phenomena there is a zone of varying concentration with position and that is say the zone E. So, similar experiment, but with different initial concentration that is the C_B say; in this case the C_B value is different from the previous one. And, here we see that end result is similar; that means, you have a clear fluid portion or the zone and a sedimented portion. But, in between the steps are different that this E here the concentration of the solid particles actually varies with the position. And, this zone basically grows up with time and this steady portion of the concentration vanishes after a certain time.

So, this portion basically dominates in the next step or in this settling step that here between the clear liquid zone or the clear fluid zone and the sedimented portion there would be a zone where the particle concentration varies with position or in the different direction. It is not uniform as was in the Type 1 that we started with the concentration C_B. Now, when Type 1 or Type 2 will occur? This we can identify from the flux plot; we will see that, but before that similar to the previous observation; if we here also look at the height of the interface versus time graph that is the height versus time graph, we see that this is the height of the interface and this is the time.

Similar to the previous observation we have the interface between clear liquid or fluid and the suspended other portion that is the B, that is steadily decreasing. Here this zone E there is a range of concentration because it is not of uniform concentration. So, let us say we have a range of E minimum that is nearer to this zone B and E maximum that is nearer to the suspended or the settled particles or settled zone that is the overall range. So, which means we have two other interfaces; that means, the BE_{min} because if we say that this is; here somewhere we have the C min E min concentration. And, here somewhere if we have the E max concentration; that means, this is the range of E that we have.

So, BE_{min} we see that steadily rises and this E_{max} and S interface that is this interface also rises, but with a lesser steepness of the slope. So, Type 2 in a broader sense occurs when the interface between this zone B and the suspension of concentration higher than B, but lesser than S these two zone rises steadily or more rapidly than the interface concentration between this zone B and zone S. If that happens then we land up with Type 2 of settling phenomena. So, this is what we discussed in the last class; continuing with this discussion the reason why such kind of thing happens or let us say typically these settling tests, this phenomenon are observed more or less accurately in case of fine particles or dilute suspension, ok.

So, in case of concentrated suspension there will be some deviation from this observation or in fact, the reason of having these two types; one of the major reason behind this is that there is a significant size distribution of the suspension or the particles that this suspension consist of. So, if there is this significant range of size distribution of the particle then such this Type 2 phenomena can occur, ok.

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So, what happens with the concentrated suspension is that the effective density and viscosity of the fluid are increased because, there is a large deviation between the two extreme or the large difference between the two extreme size of the particles. There is a huge size range considerable size range; so, this the phenomena becomes that as if the larger particles are suspending or the settling with respect to the suspension that consists of smaller one. And, in that case what happens this effective viscosity and density that enhances. Now, the other thing that happens that displaced fluid by these downward moving particles ok; so, this displaced fluid that is moving upward it becomes considerable.

Their movement becomes considerable in the concentrate suspension and that leads to the apparent settling velocity to be lesser than the actual velocity relative to the fluid. So, as the displaced fluid and its upward movement increases; quite naturally the apparent settling velocity becomes lesser and lesser compared to the actual velocity relative to the fluid. The other reason of this gradient along the position that the concentration varies through the position in a certain zone is that the near wall particle velocity gradient, that is around the particle velocity gradient in the fluid increases due to the restricted flow area, due to the concentrated suspension. There are so many particles side by side or around one particle there are too many particles, the population increases.

Also, what happens that when this larger particle moves downward, it also drags the smaller particles with them? So, the smaller particles become becomes accelerated and it changes the whole movement inside the suspended zone. On top of that if flocculation happens in ionized solvents that typically happens that results into increased effective size of the smaller particles and it, it increases the particle Reynolds number increases. So, this altogether changes the dynamics of this settling period or the settling regime. So, all these regions contribute to these different types of settling phenomena that is observed and, particularly the second type of this settling if there is a significant size range of the particle exist in the suspension.

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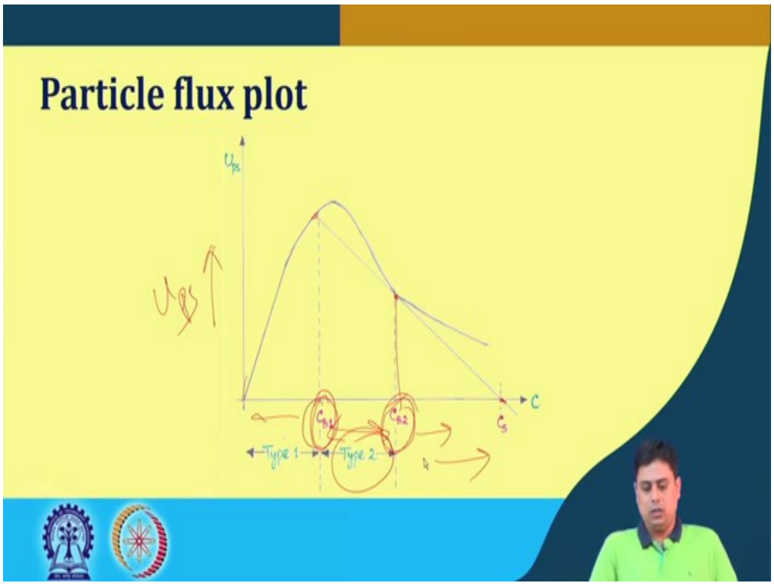

So, now if we look at the particle flux plot, we see we can basically determine that when Type 1 or Type 2 will occur; the onset of these settling periods or the settling criteria. How it happens? If we look at this flux plot we see that this is the y coordinate is our particle flux velocity and this is the concentration in the x direction. This is the typical flux plot we have seen that there is a maximum point and there is a inflection. Now, the point is that at this sedimentation concentration C_S, after complete sedimentation at this concentration an U_p is equals to 0, U_{ps} is equals to 0 at this point if we draw a tangent to this curve, the point where basically the point where it touches this tangent and where it intersects; these two concentrations are of significant importance.

Type 1 settling will occur, if the initial concentration of the suspension is lower than C_{B1} which is this one. That the point where this line intersect the curve and the point where it is tangent ok, there that point and in between this region we can have Type 2 settling. And, if we cross this C_{B2} value eventually this again fall back to Type 1 type of settling. So, if we analyze this flux plot we can understand that when the Type 1 or Type 2 will happen because, this categorization or the type of settling is dependent on the initial concentration of the suspension. The suspension concentration that you start with the experiment or the observation.

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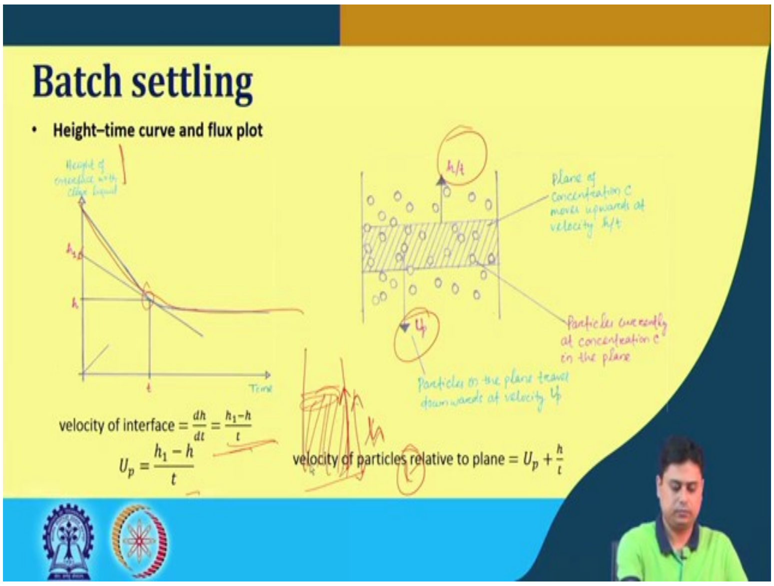

Now, if we try to find out that the relation between or how to construct the flux plot from height time curve because, this is what we measure the height time curve. Let us say this is the typical curve or the typical line that we have got from a suspension at a certain time t of concentration C ok. And we have observed the height from the bottom of the vessel to be h; that means the interface of the clear liquid zone and the suspension that is at a distance h from the bottom. At a time t we have measured that height or we can get that height from this height versus time data.

So, at this point a tangent to the curve will give us the velocity of the interface which is

$$\frac{dh}{dt} = \frac{h_1 - h}{t}$$

where, h_1 is the point of intersection of this tangent line and the y axis that is the height of interface with clear liquid. This is the height of interface with clear liquid. Now, this interface velocity is also the particle velocity that is at the interface relative to the wall which means we can write that

$$U_p = \frac{h_1 - h}{t}$$

Now, let us say imagine the scenario, that we have this kind of a visual that there is a portion of concentration C where there are some particle and the particles on this plane traveling downward with a velocity U_p.

And so, this is the interface that is say settling or coming downward and then let us consider. So, at this time t if there is a propagation of higher concentration of suspension upward because, the point is that the clear liquid and the suspension interface is moving down. As well as if you look at this suspension and the sedimentation interface that is actually increasing or moving upward. So, the higher concentration zone is actually filling up to a certain value until unless these two matches to a certain or the critical value.

So, the plane of concentration say C moves upward at that time t and has come to a height h. On one hand we are saying that this is the h at time t, where we have a clear liquid and the suspension zone. So, at that this time the concentration of C, this C concentrated suspension has actually traveled that means, to a height h. So, the velocity of that plane that is propagating from downward is basically h/t. So, the particle relative velocity is basically

velocity of particles relative to plane¿ $U_p+\frac{h}{t}$

This is the particle velocity relative to this plane of concentration C. So, with this velocity how many particles are crossing this interface?

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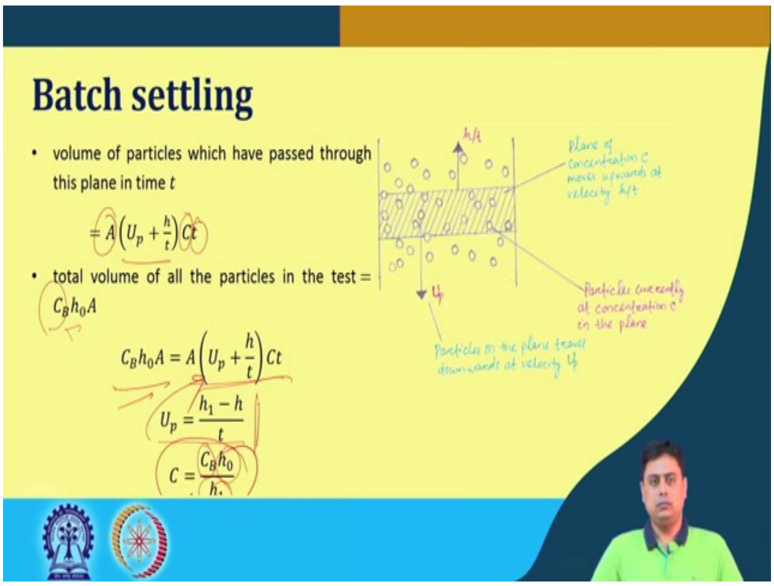

So, the volume of particle which are passed through this plane at time t is basically the cross-sectional area multiplied by its velocity, multiplied by its concentration and time.

Volume of particles which have passed through this plane in time t ¿ $A\left(U_p+\frac{h}{t}\right)Ct$

This gives us the volume of particle, that have passed through this plane at time t ok. Now, the point is that this clear interface between the clear liquid and the suspension is coming downward or moving downward. So, which means this plane of concentration C is having an interface with a clear liquid which means all the particles in the suspension have actually crossed this interface; so, that that is why there is a clear liquid at the top. So, the total volume of the particle in the whole suspension is this initial concentration multiplied by the initial height multiplied by the cross-sectional area (¿ $C_B h_0 A$).

This all particles have basically crossed this interface of concentration C. So that means,

$$C_B h_0 A = A\left(U_p+\frac{h}{t}\right)Ct$$

and from this we can find out the value of U_p. This is already we have seen this U_p,

$$U_p=\frac{h_1-h}{t}$$

replacing this U_p here in this expression we find out what is the concentration at that time which is the initial concentration multiplied by the initial height divided by the h_1.

$$C=\frac{C_B h_0}{h_1}$$

h_1 was the tangent at the point at that particular time t that intersects the y coordinate, that is of interface height with the clear liquid that is the interface of clear liquid and the suspension that height that we monitored.

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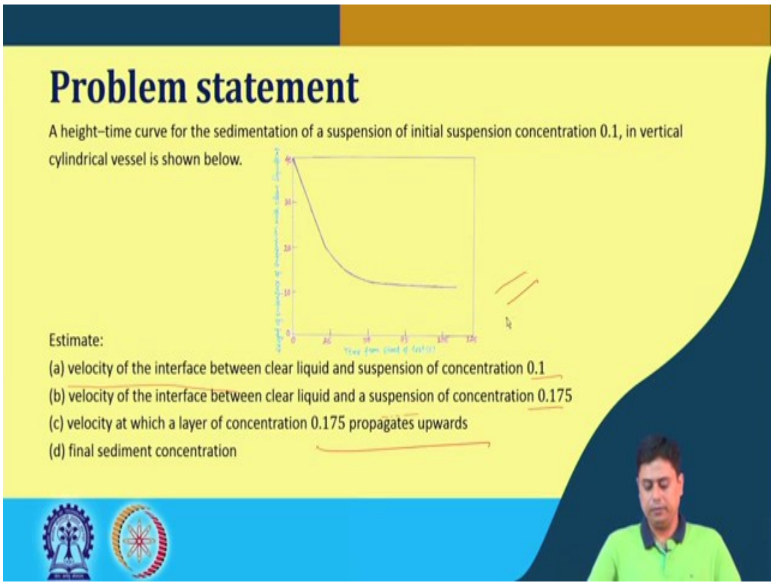

So, if we look at one example then possibly the scenario would be much more clear. So, let us say a height versus time curve for sedimentation of a suspension of initial concentration 0.1, in a vertical cylinder vessel is shown below. This curve we are seen that this is our height versus time curve.

Now, we have to estimate the velocity of interface between clear liquid and suspension of concentration 0.1. We have to find out the velocity of interface between clear liquid and a suspension concentration of 0.175. The velocity at which the layer of concentration 0.175 propagates upward and the final sediment concentration. So, these things we have to find out from this graph or the from this curve, how do we do that.

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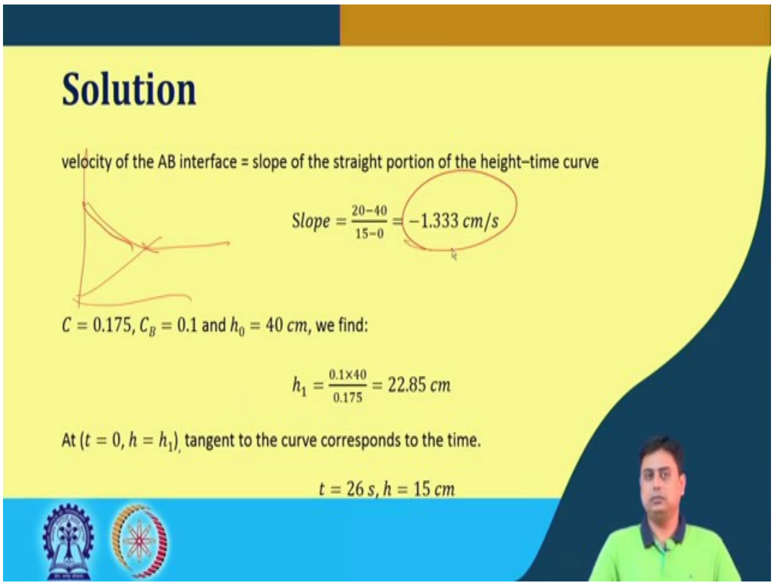

So, the point is that the velocity of this if we say A is the clear liquid portion and B is the suspension, then this AB interface is basically the slope of the straight portion in the height time curve. This is what we have seen earlier as well, that is the AB curve this was this thing. So, this straight portion slope is basically it comes out to be 1.333 cm/s, if we draw that curve.

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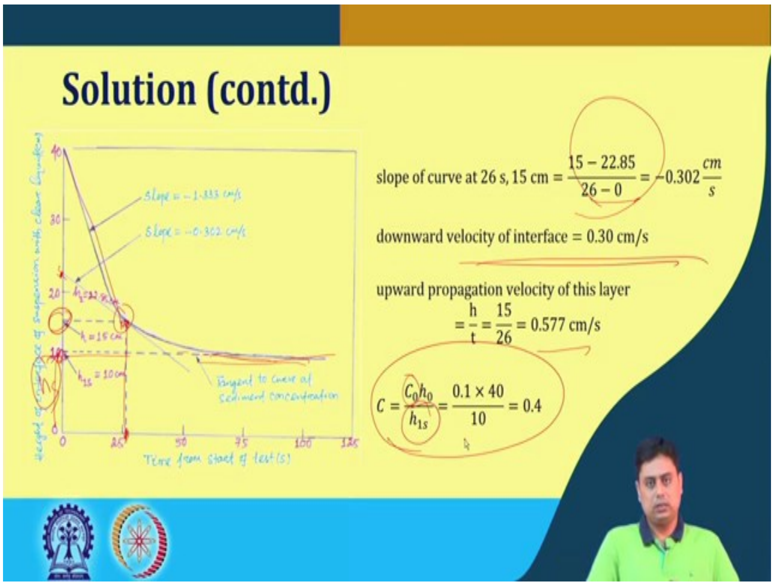

So, if we draw that this slope ok, this we can this straight portion from the graph we can find out this value.

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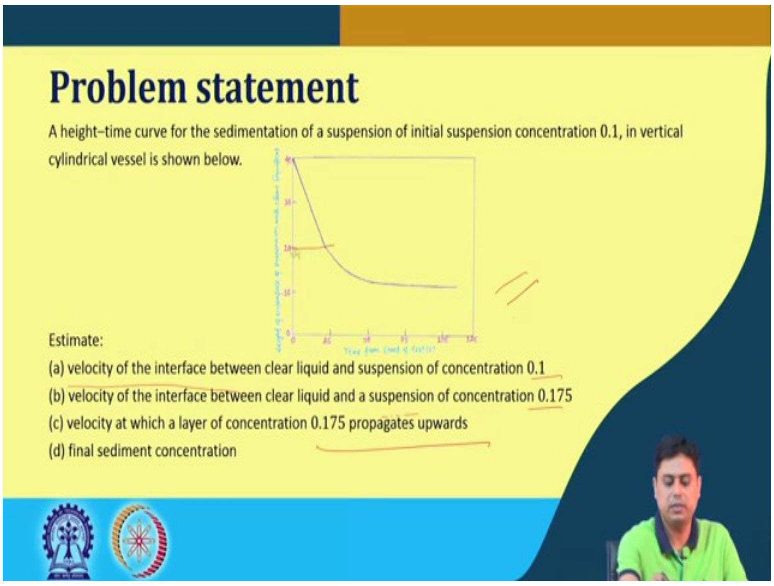

So, basically this is a straight portion. So, 40 minus 20 divided by 0 minus 15 fine. So, we can easily find out what is the slope of this portion that would be our result for the first part, that is the velocity of inter phase between clear liquid and the suspension of concentration 0.1. Because, this is the curve that is given for the initial suspension concentration of 0.1. Now, the concentration is mentioned at 0.175; we have to find out what is the velocity of interface between this here clear liquid and this section. So, in this case we have to at first find out what is the h 1. How do we find the h value?

Because, we know this relation that initial concentration is given, initial height is given ok. So, for C 1 see this new C we find what is h 1 that is 22.85.

$C = 0.175$, $C_B = 0.1$ and $h_0 = 40\,cm$, we find:

$$h_1 = \frac{0.1 \times 40}{0.175} = 22.85\,cm$$

Say this point; this is the h_1, fine. So, from this if we draw the tangent to the curve, the point it touches we get the time and we get the time as 26 s; tangent to the curve from this point that is t is equals to 0 and h is h_1 that gives us the corresponding time for this concentration. And, this concentration gives a value of height of 15 cm so; that means, we know from the bottom of the vessel at 15 cm we have this interface of 0.175 and the clear suspension.

Once we have that again the slope at the curve at 26 s and 15 cm; this slope will give us the value of interface velocity from the graph we can calculate that, that is 15 minus 22.85 divided by 26 minus 0, that gives us the downward velocity of the interface.

$$slope\, of\ curve\, at\, 26\, s, 15\, cm = \frac{15-22.85}{26-0} = -0.302\frac{cm}{s}$$

And, the question was then that what is the upward velocity of this layer 0.175? And, that upward propagation velocity would be h/t, because at that time it should have reached that value of height h that is 15 cm which is 0.577 cm/s

$$upward\ propagation\ velocity\ of\ this\ layer = \frac{h}{t} = \frac{15}{26} = 0.577\, cm/s$$

and the last part was the final sediment concentration.

So, how do we get that final sediment concentration? Final sediment concentration requires the value of initial concentration, initial height divided by the final height. Now, how do we know this final height? If you draw a tangent to this sedimented portion, the point where it intersects this y axis that would be the height for this concentration, the sedimented concentration. This plateau is basically the sedimented portion, draw a tangent there where it intersects we get that is the final height of the sedimentation. We place it; we get the value of the concentration as 0.4.

$$C = \frac{C_0 h_0}{h_{1s}} = \frac{0.1 \times 40}{10} = 0.4$$

So, which means we can see that we can draw the flux plot from this height versus data because, this is the final line, the final point of sedimentation. The initial point we knew that is 0.1, this is the 0.4; we know the slope of this A B. You can now draw this whole chart or the whole curve. I will stop here; we will see you in the next class with another problem to clear this concept further.

Until then thank you for your attention.