Fundamentals Of Particle And Fluid Solid Processing
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Lecture - 54
Fluid- solid transport (Contd.)

Hello everyone and welcome back to the class of Fundamentals of Particle and Fluid Solid Processing.

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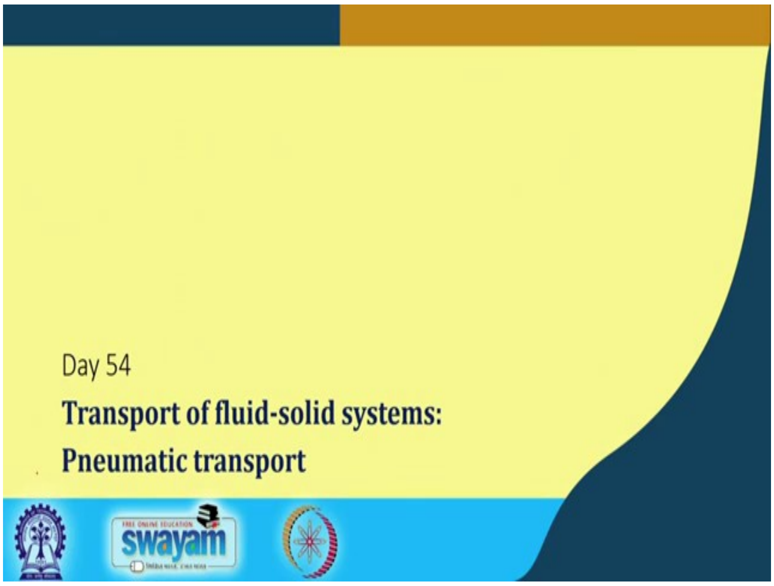

We were in the transport of fluid solid systems and we had completed in the last class the slide transport. Today, we will see the fundamentals about the pneumatic transport.

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So, pneumatic transport as I mentioned earlier when the fluid phase that carries this solid particle is the gaseous phase. So, the transport of particulate solids in the presence of a gas is called the pneumatic transport or pneumatic conveying. Now, these are widely applied in transporting a various range of particles, that is say starting from wheat flour, wheat grain, plastic chips or even coal.

There are two categories or two types of this pneumatic transport depending on the solids loading or the solids concentration. One is like the slurry we had it is the dilute or the lean suspension and the other one is the dense phase transfer. So, in dilute or lean suspension, we require a large volume of air at a very high velocity.

So, like in slurry transport that we mentioned, that most widely used liquid was water. In this case the gaseous phase is mainly here. So, we will mostly talk as the gaseous phase as here in this section. Now, in case of dilute phase, we require huge volume of air that would be required at a very high velocity to take these fine particles or the particulate solids from one place to the other.

In case of dense phase transport the particles are not fully suspended or all the particles in fact, are not in suspension. So, but still why this transport or this kind of transport we will be talking about or why we will be studying, because it was also widely applied till a certain period in the industry. And, even in some cases it is used, although the particles are not fully suspended, but due to the low requirement of air volume, which in terms of the lower mechanical energy despite very high pressure requirement. It is beneficial in transporting the particles for say a shorter distance or even in a straight pipe.

Why it is so, we will see that when we go into the details of the flow regime. Now, since here the velocities of the air that induces the movement of the particle is lower; that means, it offers lower degradation of the pipeline network by attrition or the erosion. So, these are the benefits we had in dense phase transfer despite the particles are not fully suspended.

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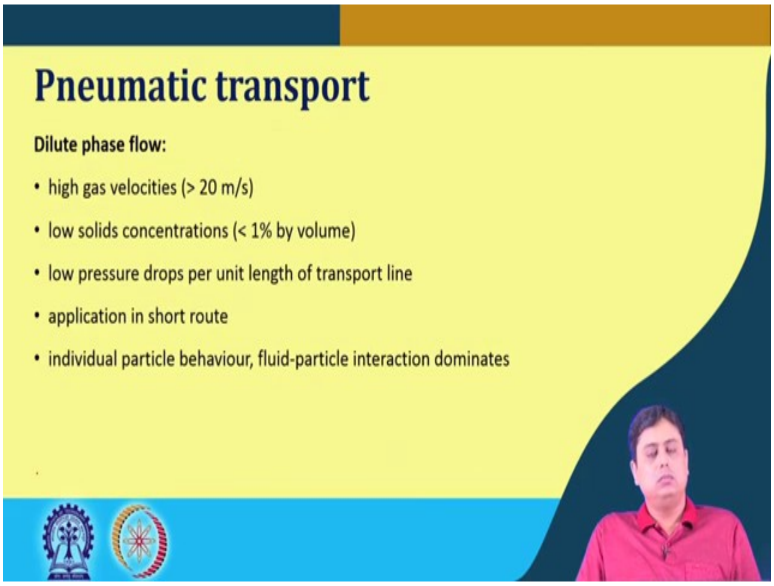

Now, if we go into the details of the dilute phase flow or the transport and the difference between the dense phase transport these two are basically characterized by certain parameters or classified by certain parameters. This can be detected by looking at the gas velocities immediately.

So, this dilute phase flow can immediately be detected, if there is a very high gas velocity say above 20 m/s. And, slow solid concentrations say below 1 %t by volume. As well as low pressure drop per unit length in the transport line. If, we had these things in a certain working condition we can detect that this is the dilute phase transport that is happening.

And, it is also applied in short route ok, but in certain cases it is used for prolonged routes as well. In this case since there is a very small concentration of solids present in the air the each particles behaves as individual particles. So, individual particle behaviour dominates as well as the fluid-particle interactions, that dictates the property of this flow.

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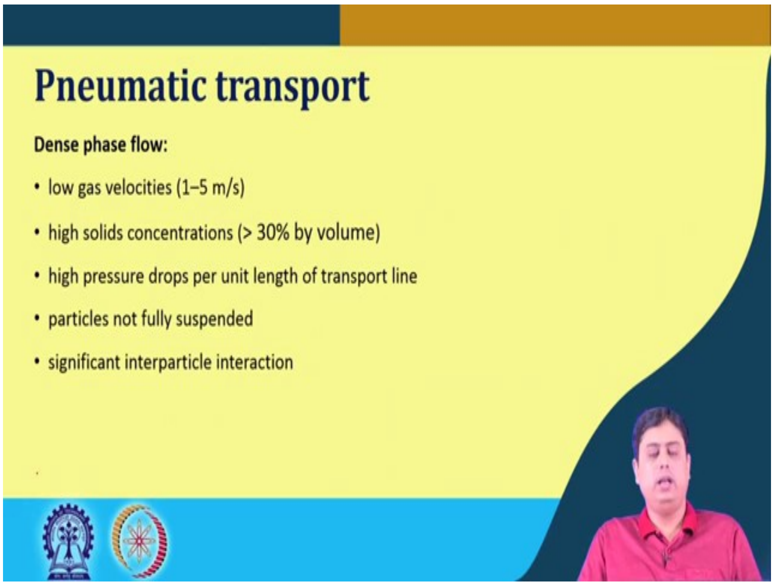

In the contrast in dense phase flow, it can be immediately recognized by the low gas velocities in the range of 1 to 5 m/s, high solids concentration say more than 30 % by volume and high pressure drop per unit length of the transport line. In this case as I mentioned earlier, that the particles are not fully suspended I mean all the particles are not fully suspended.

In ideal case or in one ideal scenario of the dense phase case, what would have been the whole cross section would be filled with the solid particles, but we can logically understand that that scenario can lead to choking of the flow. Now, since there are multiple particles in a close proximity in a denser manner.

So, there is a significant interaction between the particles, which cannot be neglected like that can be done in case of dilute phase transport. Now, there is no such clear distinction or clear guideline to distinguish between these two flow regimes that is the dense phase and the dilute phase, but there are several atoms in order to characterize them or to classify them.

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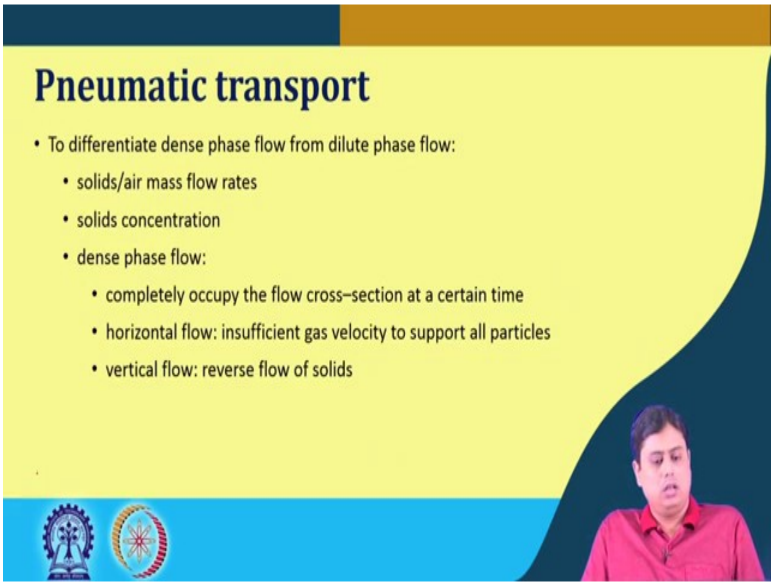

One of such shows or dictates that we can look at these parameters that is listed here, in order to differentiate the dense phase flow from the dilute phase flow. We can look at the solids to air mass flow rates or the ratio. We can look at the solids concentration in the flow, that this helps us in determining which would be the flow regime or which would be the characteristics of the flow.

So, in dense phase flow it should occupy the whole cross section of the flow at a certain time as the flow happens. In case of horizontal flow the gas velocity would be insufficient in case of dense phase flow to support all the particle to remain in suspension; that means, particle settling will happen in case of horizontal flow. Say, horizontal pipe the dense phase flow is happening.

So, we can characterize that this is a dense phase flow if we see that the particle settling are happening or say there is a saltation regime, like we have seen in the case of slurry transport. In vertical motion or when there is a vertical flow in the pipe network this pneumatic transport is happening in the dense phase flow, there will be the reverse flow of the solids.

That means, if the solid the gas phase is not able to withstand all the solid particles in the suspension. If, the reverse flow of the solids happening then we can take that this is a dense phase flow. So, these are the broad guideline by which we can differentiate between the dense phase and the dilute phase transport, in the case of pneumatic conveying.

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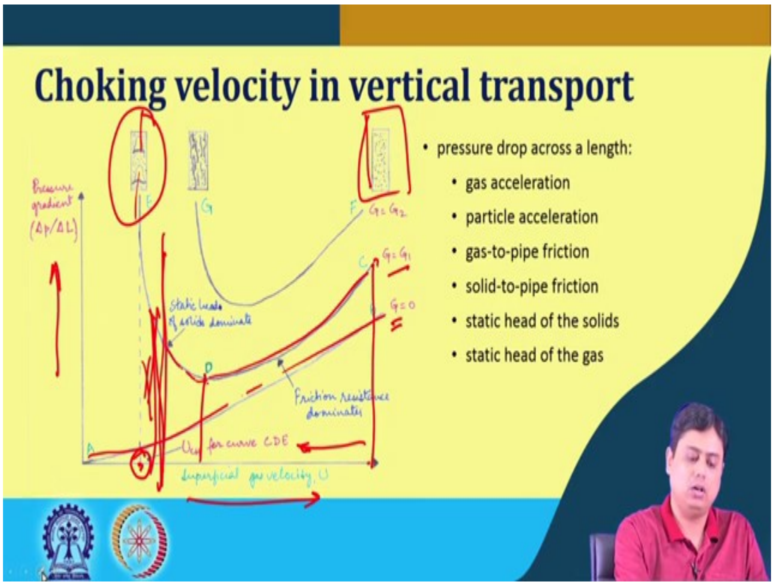

Now, in the case of vertical transport when it is say going against the gravity, now in such case the critical velocity where the operation should be maintained we call that as a choking velocity. And, in case of horizontal flow that velocity we mentioned as saltation velocity.

So, in horizontal case, it is the saltation velocity and in case of vertical flow, we would mention these critical velocities and the choking velocity. Now, this is what is important or this detection are what important in order to maintain the flow, because we our goal is to transport the solids by this gaseous phase or the air.

So, we have to know that, what is the minimum air velocity that is required to have that, to achieve that. Now, that should be done with the as minimum air as possible, because then the energy cause the energy requirement or the air requirement everything is lower. And, with the minimum amount of air the mean velocities would be lower so, the abrasivity and all these things can be taken care of.

So, if we look at the vertical transport in case of pneumatic conveying, say this line this AB where x axis is the superficial gas velocity and y axis is the pressure gradient. So, in case that this is a simple air flow is happening without any particle, then it would result in this this line AB, where *G* stands for the solids loading or say the mass flow rate of the solid.

So, here there is no solid in this case. So, this is basically the frictional resistance. Now, when we introduce solids or say the dilute phase transport is happening. In this case for a certain solids concentration or the mass flow rate of the solids, we see that at very high velocity, the concentration of the bed is lower, it is fully suspended and the kind of say dilute phase transport is happening at a very high velocity. Now, as we go down or decrease the velocity, the frictional resistances becomes lower, the pressure drop becomes lower, but after a certain point the static head due to the solid particles becomes dominant.

And, and actually increases the pressure other pressure drop requirement. So, the pressure drop again increases. Now, at this point the gas velocity is basically not able to penetrate the solid bed or say the solids are not being correct with the gas velocity that is provided. And, if we further decrease that, this scenario would happen, when the solids will completely block the channel and the flow would not be there, that velocity we called the choking velocity.

Now, here we can see in the bed structure that there is a kind of bubble passing through the fluidized bed, this kind of scenario is happening that we have seen in case of fluidized bed, kind of a bubbling regime is there. Now, in this case there is a considerable fluctuations of the pressure that can be obtained through the vertical plane.

So, it is basically the slugs of air that would be moving at an irregular time or the irregular interval. So, this velocity we called the choking velocity. And; that means, we have to operate, the bed in this regime or higher than this value the choking velocity, but somehow near to this range, there is some unstable condition of the flow behaviour.

So, it is better to operate a far distant from this choking velocity, because nearer to the choking velocity, there is a transition zone, there is say it can move towards this choking velocity at any point of time. The control is very poor in that regime.

Now, if we increase the solids concentration in the feed; that means, the solids loading, if we increase, what happens this choking velocity also increases. The requirement of the velocity in order to choke that also increases. So; that means, the choking velocity can be arrived by two conditions; one is that if we fix the solids loading and decrease the velocity, we can arrive at choking velocity or for a particular superficial gas velocity. If, we increase the solids concentration, then also we can as arrive at the choking velocity.

So; that means, once again if we decrease from this dilute transport where the concentration is lower and if you decrease the velocity the superficial gas velocity, the bit concentration increases and at a point, it is not able to further which and the height of the this static head of the solid particles and the pressure drop again increases. And, after regaining critical limit it basically blocks the flow and that is called the choking velocity.

So, this pressure drop along the length basically dependent on certain factors or it is a combination or the contribution from all these parameters, which are the pressure drop due to gas acceleration, the pressure drop due to particle acceleration, the gas to pipe friction, that contributes to the pressure drop, solid to pipe friction, static head of the solids and the static head of the gas.

So, the combination of all these parameters, contribute to the overall pressure drop across a length. Now, so, which means prediction of choking velocity is important, but unfortunately there is no as such critical or say the theoretical development on the choking velocity.

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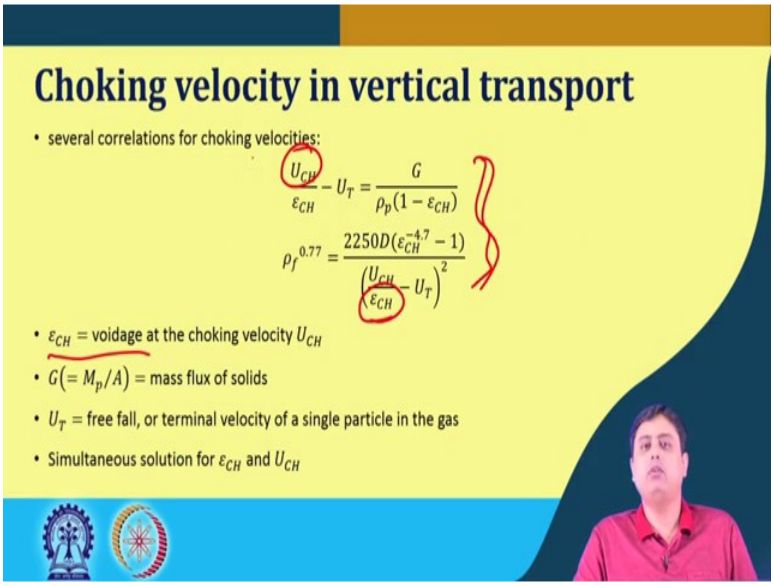

There are several experiments several correlations have been proposed for choking velocities and one of such is given here.

$$\frac{U_{CH}}{\varepsilon_{CH}} - U_T = \frac{G}{\rho_p(1-\varepsilon_{CH})}$$

$$\rho_f^{0.77} = \frac{2250\,D(\varepsilon_{CH}^{-4.7}-1)}{\left(\frac{U_{CH}}{\varepsilon_{CH}} - U_T\right)^2}$$

So, where U_{CH} is the choking velocity ε_{CH} is the voidage at the choking velocity G is the mass flux of the solids, which is M_p/A, the cross sectional area for the flow. U_T is the free-fall or the terminal velocity of a single particle in the gas. And, we have to solve these two expressions as above simultaneously to get these 2 parameters.

So, this is one of such example that how the choking velocity can be predicted there are several correlations available and that can be taken from the literature. So, this choking velocity once again we have to avoid and we have to operate above this velocity.

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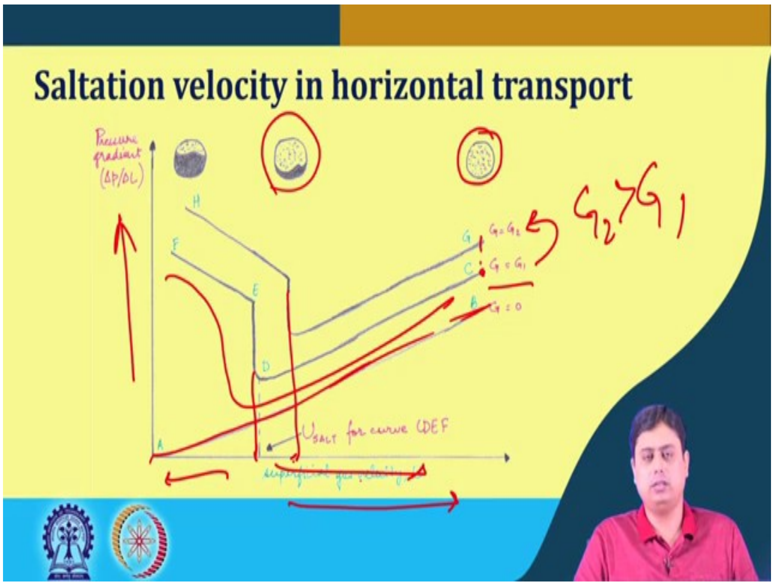

Now, similar to the vertical arrangement in the horizontal transport we can have saltation velocity. Now, here at a very high velocity this is the superficial gas velocity and this is y axis is the pressure gradient. I mean this case again at a very high velocity; we can see that the pipeline cross section is uniformly distributed with the solid particles which is we can say the concentration is lower. So, that this is a dilute phase transport.

Now, if there is no particles in the pipe it would be giving this kind of a result the superficial velocity and the pressure drop line. But, once it is introduced the solid particles are put into that system or it is conveying the solid particles, this kind of a graph would be resulting. Which shows, that as we decrease the velocity from the dilute phase transport, it would similar to the choking velocity would reach a critical velocity in the horizontal transport, where the saltation of the solid particles would take place.

What is that we have seen in the slurry transport, it is analogous to that and that velocity is called the saltation velocity? In this case the pressure drop requirements rapidly increases. And, after that if we further decrease the superficial gas velocity, the result would be that there will be a clear separation of the settled solid, which will partially block the channel or the pipe and there will be a small section or the area through which the gas will be passing through. Some of the solids will be carried with that gas phase on the air and then also the pressure drop requirement will be further higher.

So, in case of horizontal transport this saltation velocity is what demarks between the dense phase flow and the dilute phase flow. In case of choking velocity or the vertical transport choking velocity is what defines or demarcates between the dilute phase transport and the dense phase transport.

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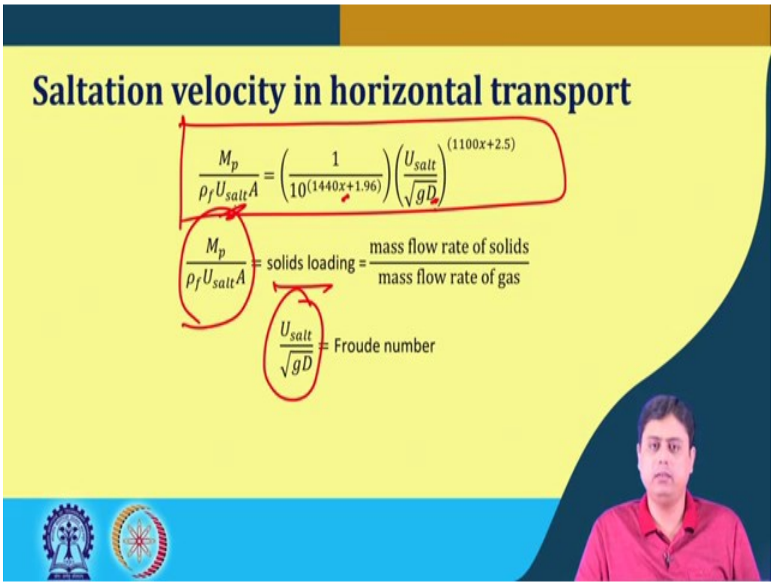

Now, similar to this choking velocity calculation in the vertical transport, there are several correlations for the saltation velocity. Now, in the saltation velocity case as we have seen in the case of choking velocity, if we increase the solids concentration further the saltation velocity also increases from G_1 to G_2; that means, $G_2 > G_1$.

So, the mass flux of the solids if it is increased the pressure drop require the pressure drop increases as well as the choking velocity or the salitation velocity in the case of horizontal transport also increases. So, in this case also we can arrive at the saltation velocity for a particular superficial gas velocity by increasing the solids concentration or for a particular solids concentration, if we decrease the velocity.

So, superficial gas velocity, we can arrive the choking the saltation velocity in this case. Now, similar to the choking velocity calculations in saltation velocity also can be calculated from several correlations, there is no such theoretical development on this, but these empirical correlations hills in calculating the saltation velocity in the horizontal transport.

Now, one of such example or the correlation is presented here and this is possibly the simplest kind that is shown here.

$$\frac{M_p}{\rho_f U_{salt} A} = \left(\frac{1}{10^{(1440x+1.96)}} \right) \left(\frac{U_{salt}}{\sqrt{gD}} \right)^{(1100x+2.5)}$$

Otherwise, in the other correlations there are several parameters or several complexities or complex relations is involved, where $\frac{M_p}{\rho_f U_{salt} A}$ is called the solids loading, which is defined as the mass flow rate of solids to the mass flow rate of gas.

And, this parameter or this quantity $\left(\frac{U_{salt}}{\sqrt{gD}} \right)$ we call the Froude number, where x is the diameter of the particle D is the diameter of the pipe, g is the gravitational constant ρ_ff is the density of the fluid; U_{salt} is the saltation velocity. So, what we have seen today, the introduction to pneumatic conveying 2 different zones or 2 different extreme of this transport condition, that is the dilute phase transport and the dense phase transport, what are the characteristics of these 2 in case of dilute phase transport horizontal as well as the vertical flow. How do we arrive at the choking velocity and the saltation velocity choking velocity in case of vertical flow, saltation velocity in case of horizontal flow?

So, when we will further mention about choking that would imply that the orientation of the pipe is in vertical direction and when we talk about saltation it means it is in the horizontal direction. So, these two velocities how to calculate them how to determine them this we have seen in today’s lecture? We will continue this discussion and we will see you in the next class.

Thank you for your attention.