Course: Adsorption Science and Technology: Fundamentals and Applications

Instructor: Prof Sourav Mondal

Department: Chemical Engineering

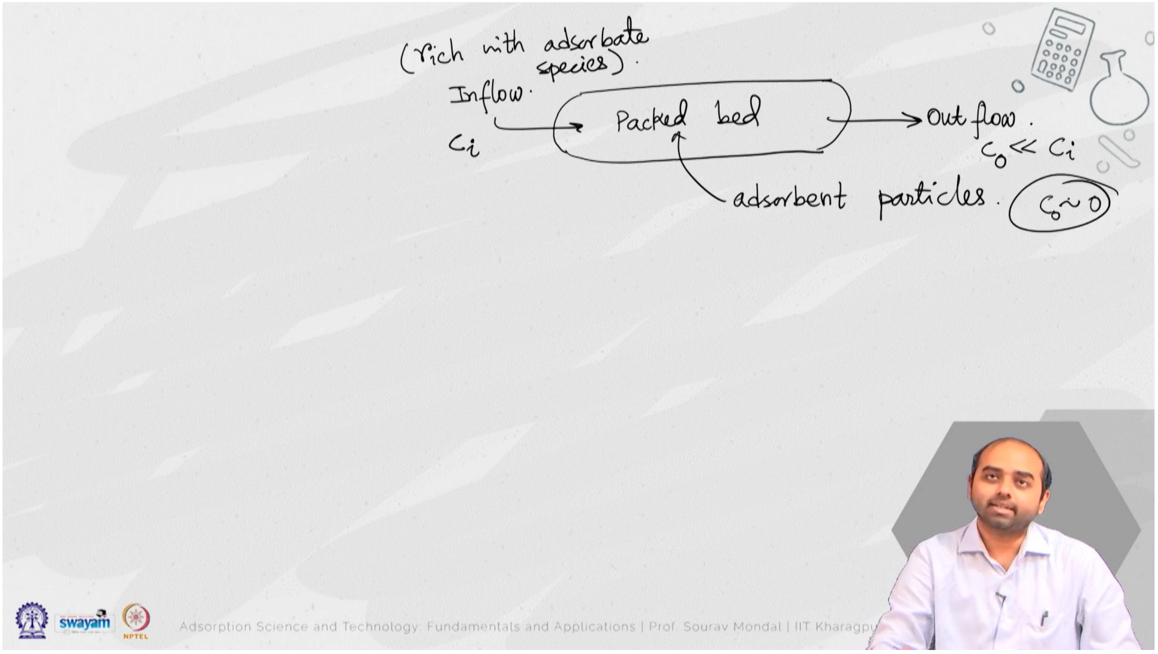
Institute: Indian Institute of Technology Kharagpur

Week 05

Lecture 21 | Fixed Bed Adsorption

Hello everyone. Welcome to week 5 of this course on adsorption science and technology. In this week we will be focusing on fixed bed adsorption and this is particularly very important for continuous operation because fixed bed systems can be operated you know for a scaled up scenarios. And, this can be operated for you know at a constant outlet concentration almost close to 0 because of continuous adsorption which is happening inside this fixed bed. So, we will talk about more about this on how to model the adsorption front and the different types of you know design equations that exist for fixed bed adsorption. So, in today's lecture we will be focusing on what is the concept of the breakthrough in a fixed bed adsorption and how this information can be you know used for modeling the performance as well as scaling up of fixed bed adsorption. So, let us try to understand the scenario what happens inside of the fixed bed adsorber.

So, this fixed bed adsorber is nothing, but a packed column it is a packed column. We try to give you some overview of the operation. So, this is generally a packed bed, which is filled with adsorbent particles and there is a continuous inflow and outflow. So, in the inflow is rich with adsorbate species.



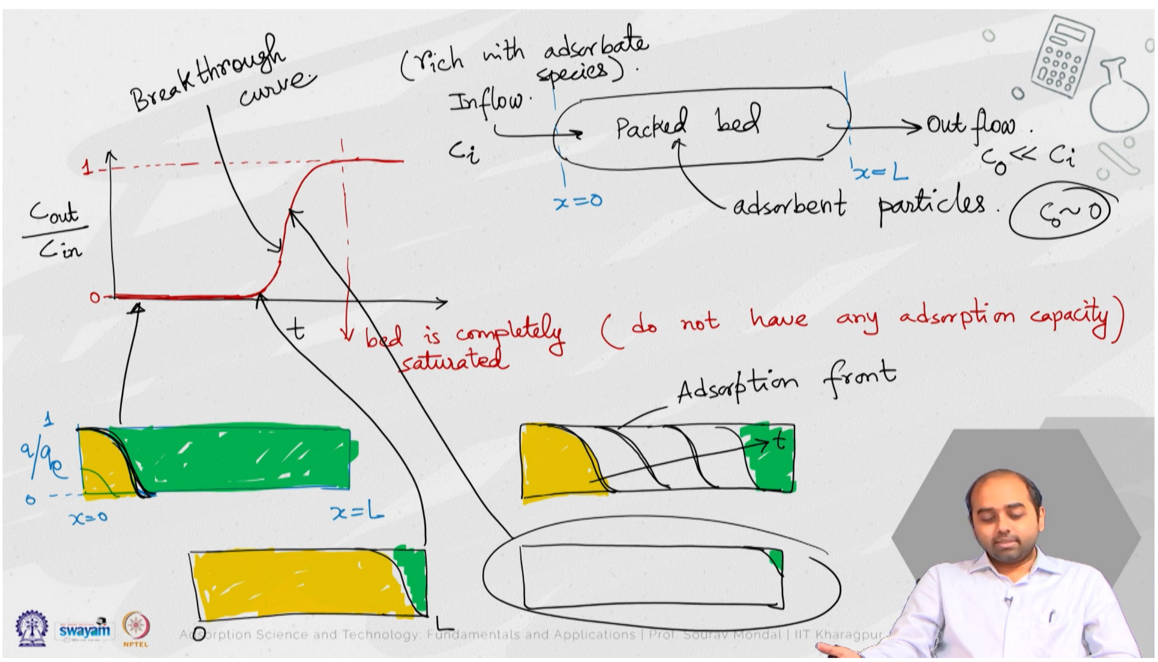
Let us call the concentration as C0 and the outlet is actually, as it moves through this packing of the bed the species is actually the adsorbed or separated in this bed. And as it goes away or it goes out the stream is actually devoid of any of these adsorbate. So, the concentration of the adsorbate molecule C is much much smaller than the inlet concentration C0. Let us denote the inlet concentration as Ci and the outlet as C0. So, the outlet concentration is much much smaller almost equal to 0 as long as the bed is adsorbing in the output state. So, if you try to plot the scenario of C0 outlet concentration with respect to the inlet concentration with respect to time.

So, if you are measuring the outlet concentration with respect to time. So, this appears that is at initially when the bed is adsorbing as long as the bed is adsorbing this will be 0 or close to 0 values, and then when the bed no longer adsorbed then the concentration will rise and then will be a point when the bed is completely saturated with the adsorbate species this will further no longer have or do any adsorption. So, this is the point, when the bed is completely saturated and it do not have any usable capacity, it do not have any adsorption capacity at that point. So, what happens inside this adsorption how does the concentration front look like let us try to relate the concentration front at different time. So, if one tries to plot the concentration profile inside the bed.

So let us call this as like the you know this x dimension. So we call this x is equal to 0. This is like x is equal to L. It is like you consider this as x is equal to 0. This is like x is equal to L.

And the y axis we consider as like q by q0 right which scales from 0 to 1. So, initially q by q equilibrium or whatever this is the initial picture right. So, which means that only a part of the bed is actually reached equilibrium or has reached it capacity and it cannot further no longer have any adsorption. Whereas, the rest of the portion of the bed is still unutilized this is the portion which is unutilized here that can adsorb the incoming species. So, as long as the bed has some green region outlet concentration would be 0.

So, this is like the scenario when we are having here can be related to something like this scenario. Now, after some point in time this adsorption front will propagate and there will be a zone like this and slowly that front will be moving so with time this is how it will look like so there will be a zone which would be like completely you know has reached its saturation level and there will be a portion where still there is some capacity left. So, like this it will proceed at different times this position will change . Why this front will not be flat will I will talk about that, but let us for this moment realize that this adsorbent front may have a gradient it may not be perfectly vertical because of some internal resistance in the dispersion and the diffusion it may not be absolutely vertical. And slowly there will be a moment when this will hit that adsorption front will actually hit the exit point or the exit level and beyond that point it will be something like this.

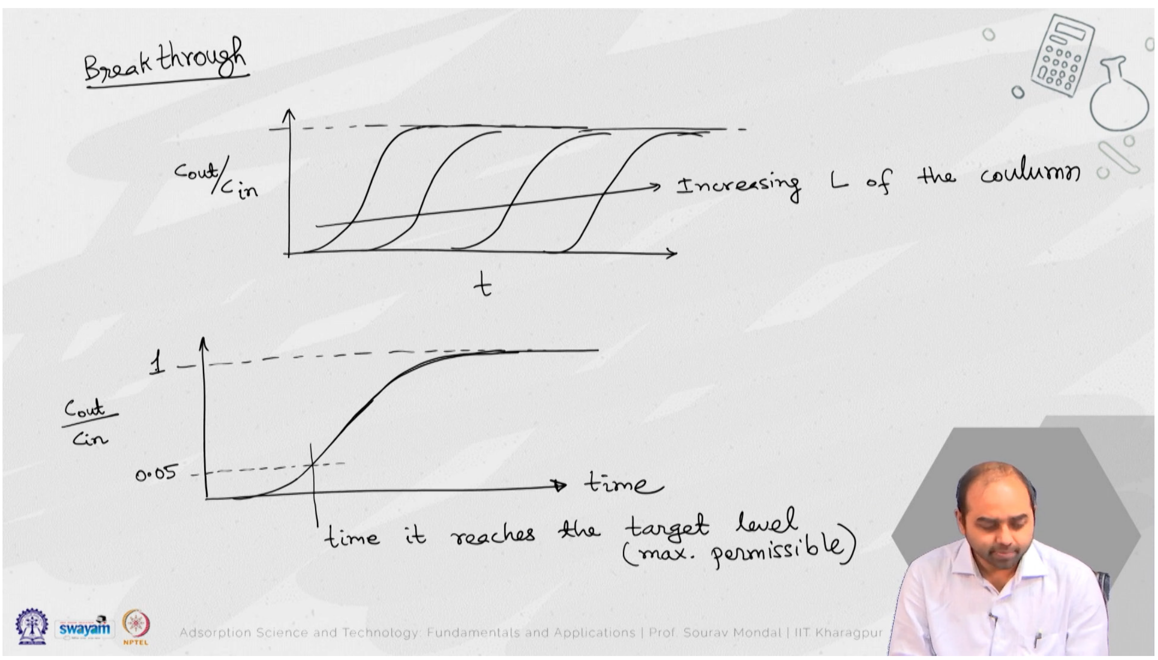


So, in this scenario, here the bed is almost now getting saturated and this is the scenario where we can relate to the scenario at this point just at the beginning of when this outlet concentration starts to rise and this is the scenario this is the scenario that is typically what you see something like here. And of course, you can realize when the outlet concentration reaches to the inlet concentration the entire bed is actually utilized and there is no green portion or usable capacity still remaining for that bed and the bed appears to be exhausted. So, this is how I am trying to relate the different scenarios in this concentration versus time profile that you get at the outlet and I am trying to relate that observation with the scenario what is happening inside with the adsorption front. So, this is what is related is you actually referred to as the adsorption front. So, these curves that I have drawn is known as the adsorption concentration front or the adsorption front and this red colour curve is referred to as the breakthrough curve.

So, even though the breakthrough curve may not have you know started or the breakthrough curve is at the concentration profile is 0, there may be a point or there is a point inside the bed where the adsorption front has moved almost from the inlet to the exit concentration. Only when that it crosses the exit you know level or the exit point the breakthrough curve starts to take this sigmoidal shape. And till that point the outlet concentration is 0. So, this is particularly the typical of these observations that is seen in this fixed bed adsorber. Why it is called a fixed bed? Because the particles are immobilized or is fixed in a packing and they do not move unlike in a batch adsorption scenario.

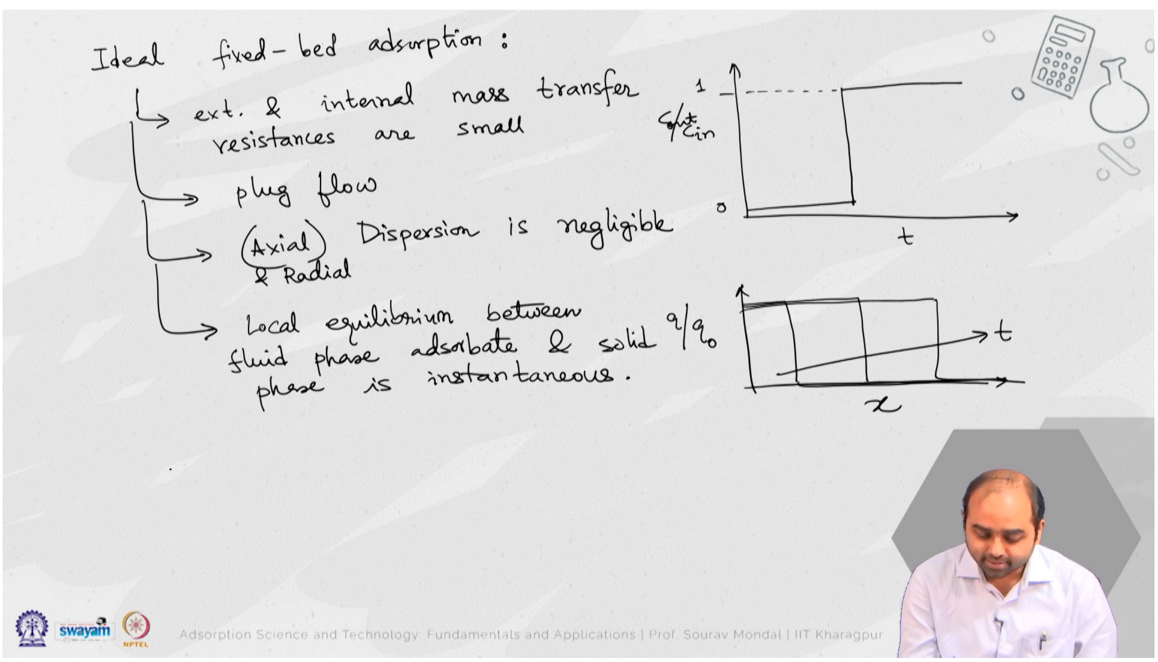
So, under these circumstances the adsorption phenomenon is giving almost a continuous steady output of a negligible concentration and these are actually great for separating a continuous stream of particles. In case of you know trying to understand more on the breakthrough one can easily relate that this breakthrough profiles this c out by c in profiles with respect to time looks like this. So, with increasing t, you know length of the absorber. So, this is increasing length of the column the breakthrough behaviour would be extended or the onset of this breakthrough would be delayed which means the capacity of that bed is large and it can filter out it can work or it can perform adequately up to a longer time, and that is how you know the bed is normally scaled up so that the breakthrough time which you get is is extended and the bed has a usable more usable capacity which can essentially be used to separate or process a large volume of the liquid. Now it is important to realize here that what happens when you have this breakthrough and when you have something known as the desirable output or the permissible value of the output.

This is particularly true for you know if this is used for environmental applications often you know the if you want to remove let us say you want to have a water treatment setup and you have a fixed bed adsorption stuff column then the outlet concentration may reach permissible value or may exceed a permissible value which is much smaller than the you know the time that it takes to achieve the final you know saturation limit. So, if the breakthrough time in that case maybe something different let us draw the breakthrough column little bit like not steep, but gradual and run this intentionally. And let us say that at this particular point which may be like 5 percent or 10 percent whatever the absolute value of that particular species that we are trying to separate with respect to the inlet concentration it could be like if the inlet value is very small it could be like 20 percent if the inlet value is very high this could be like 1 percent. Because, outlet concentration in absolute terms may have a permissible value like for example, if you are talking about um absorbing a particular you know component for example, phenol from waste water and if the inlet concentration is like 50 ppm and the outlet permissible value for environmental discharge is like 1 ppm, then it would be like 1 by 50 or 0.02 as the value that is permissible.



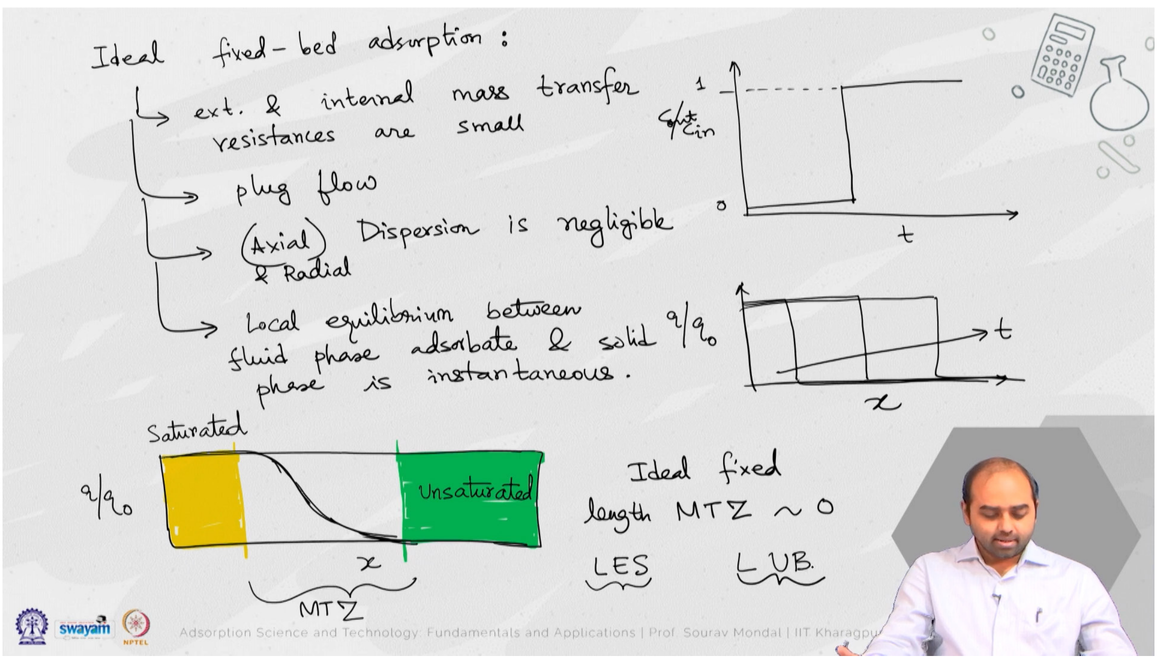
Similarly, if the inlet concentration is 10, then this could be like 0.1 could be like the permissible value. So, this time this time where it reaches the time it reaches the target level right or the you know that limiting value max permissible value. One can actually stop the operation of this bed as in that case the the bed even though it has not achieved complete saturation or complete exhaustion it may no no longer be used because the output concentration in that case or the outlet concentration in that case will give a value which is higher than the permissible level. So, in that case the entire breakthrough may not be obtained or one may not actually see the entire breakthrough or the breakthrough happening completely till the saturation limit, but instead the operation is stopped in between.

Let me try to also you know relate what do we mean by an ideal you know system and what is the scenario in the non ideal system. So, in the case of the ideal you know adsorption system right which is very important to understand here this ideal fixed paid adsorption. So the ideal situation is achieved in a fixed bed where we have a you know this perfectly vertical adsorption front or the breakthrough curve in the case of ideal adsorption column looks like this there is no gradual change in the breakthrough or there is no you know this um outlet concentration changing over a period of time so the sigmoidal function looks like a you know step function so this is like the ideal breakthrough and in this case the concentration wave front inside the column would look at different times like this. So, essentially it means, sorry this is not t, this is x, so this is like at different time. So, this is how the concentration wave front would be moving inside the you know column and essentially this suggest that there is actually no gradual change or there is no effect of dispersion and diffusion.



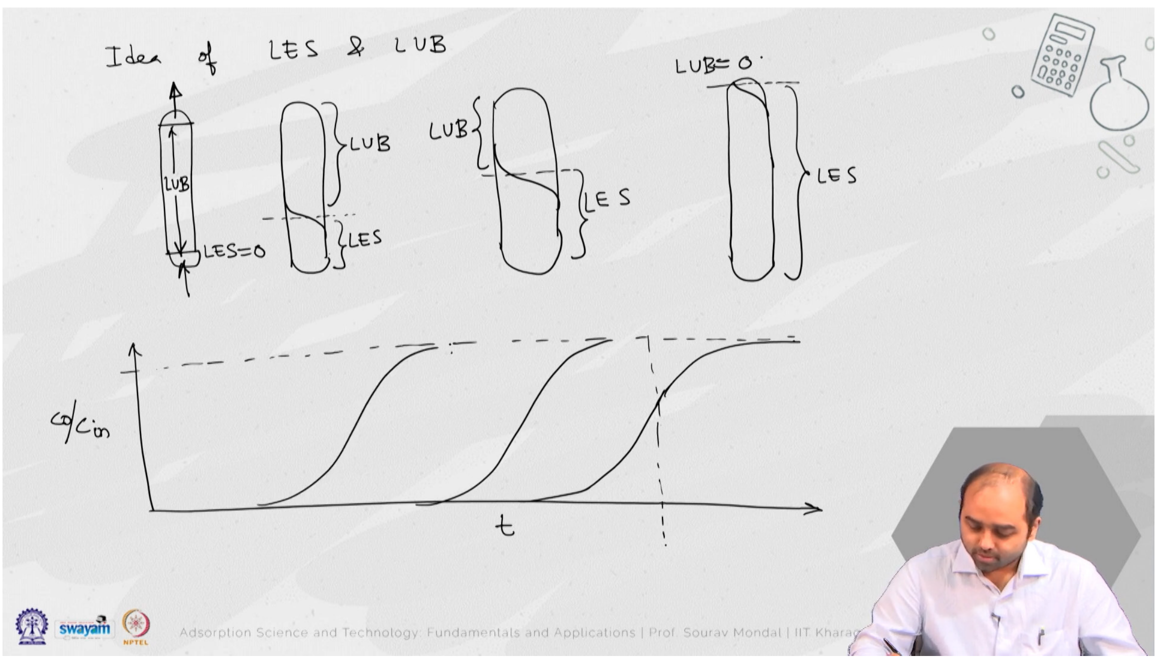
So, what are the key assumptions in having an ideal or close to ideal fixed bed adsorption is that the external and internal whatever mass transfer resistances are there. They are small. Next log flow type behavior is achieved. Axial dispersion or in general dispersion both axial and radial is negligible and finally, we say that local equilibrium between this fluid phase adsorbent and sorry fluid phase adsorbate and solid phase is instantaneous. So, these are the different assumptions based on the premise where you can think or you can relate that this wave front is actually exactly the stoichiometric wave front or shock like behavior which takes place inside this column.

But this is far I mean in most cases we will see that there is a non ideality in the system and these resistances are not small enough to be ignored. That is the reason there will be a considerable zone, which is, where the wave front, is actually not perfectly vertical not shock like instead there is a gradual change and the breakthrough curve also takes the shape of the sigmoid. So, that particular region is known as the mass transfer zone. So, if this is the you know profile that we are trying to see inside the column. So we will have one portion where the bed is like completely saturated.

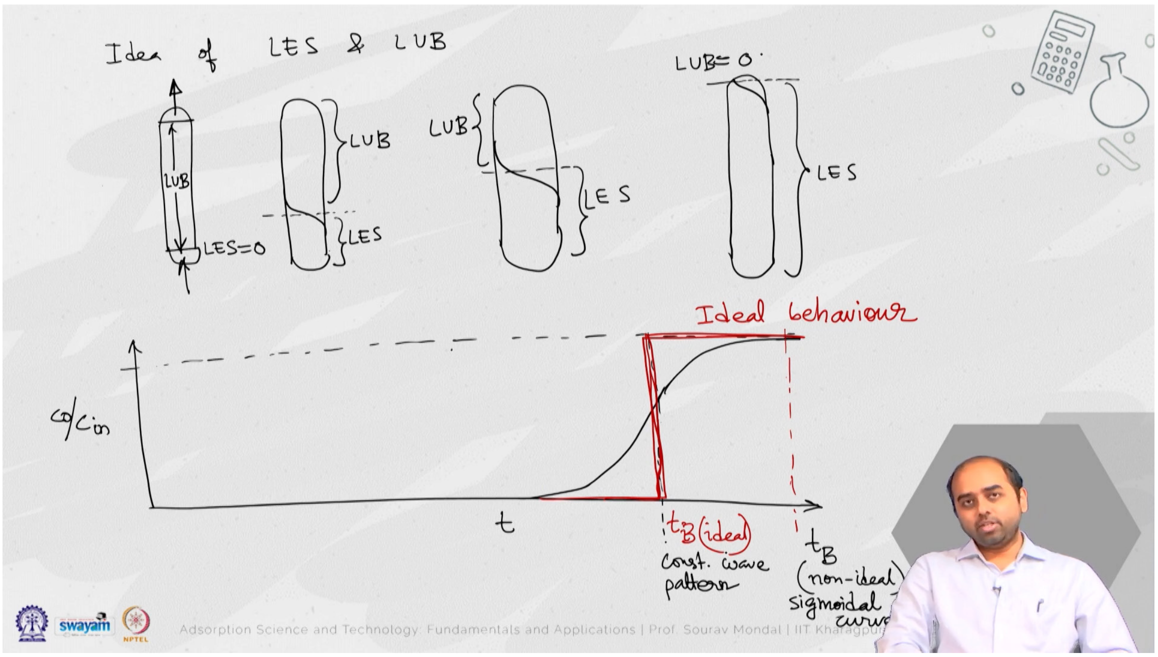


Let us call this portion as bed is like completely saturated. There will be one portion where the bed is completely unsaturated or not utilized, and the portion here is. So, this is like completely saturated, this is like completely unsaturated and this is the portion which is referred to as the sorry mass transfer zone. Now in the case of ideal fixed bed the length of this mass transfer zone is 0 which means that there is no mass transfer limitation or this mass transfer resistances which is present equilibrium is also at an instantaneously there is no dispersion etcetera either due to fluid flow or whatever you know diffusion etcetera. So, in that case the mass transfer zone is 0 and in that case this takes the shape of the you know this shock like behavior.

So, now generally this scenario of you know when the mass transfer limited sorry mass transfer zone is close to 0, the entire bed can be split into two parts like unused portion and used portions. So, which is commonly referred to as the you know length of the equilibrium section and the length of the unused bed. So, length of the equilibrium section and the length of the unused bed actually refers to the fact that you know the portion which is saturated is actually comes under the length of the equilibrium portion and the length of the unused bed is actually the unsaturated portion. Now, the entire bed can be split into these two fractions provided the mass transfer zone is equal to 0, but as you understand that the mass transfer zone is practically not equal to 0 the smaller it is the better it is, but to consider that where the mass transfer zone is like exactly halfway in between one can use this theory for scaling up or design of fixed bed adsorption column. So, let us try to see what do we mean now in the practical scenario or utilizing this idea of LES and LUB.



So, in a column. Let us say we are having this column in and out, then with time sorry we should draw it concentration profile change so here it is like LES is here and entire portion is like from here to here is like unused portion of the bed now here one can say that halfway in between is like les and this portion is LUB so this continues that is the adsorption front moves So again you can consider this to be like LES. This is LUB till a point when the entire bed is like up to this point. In that case the halfway mark reaches here. So even though there is some unutilized portion the LES is this much and LUB in that case is equal to 0. So, if I try to draw the different scenarios in the you know breakthrough profile this will take the shape of, something like this so this is the more or less the point where even though even though sorry. So, where even though the you know bed has not completely reached saturation since the length of the unutilized portion is to be 0.



So, the breakthrough profile can be approximated or can be considered that in this scenario of the LU model this is like the equivalent you know shock wave pattern in the case of the ideal behavior. So, this is what with this idea of the unutilized bed and equilibrium zone the non non ideal version where you get a typical sag model curve can be treated as the you know ideal behaviour where this is like the like the ideal time of the operation or the breakthrough time in the case of the constant wave pattern whereas the breakthrough time in the case of the real system may be somewhat later so this is like breakthrough time of ideal or constant wave pattern whereas this is the breakthrough time in the case of non-ideal system or where you get a sigmoidal you know curve and this is constant wave pattern. So, in the next class we will talk more about how this idea of the LES and the LUS can be used for modelling the you know design of the column particularly calculating its height and scaling up of the scenario. We will also see how the mass transfer zone can be modeled particularly for non-ideal systems using Klinkenberg equations and can give us a more realistic solution of the system. So with this I would like to close this lecture and see you everyone in the next one. Thank you.