**Course: Adsorption Science and Technology: Fundamentals and Applications**

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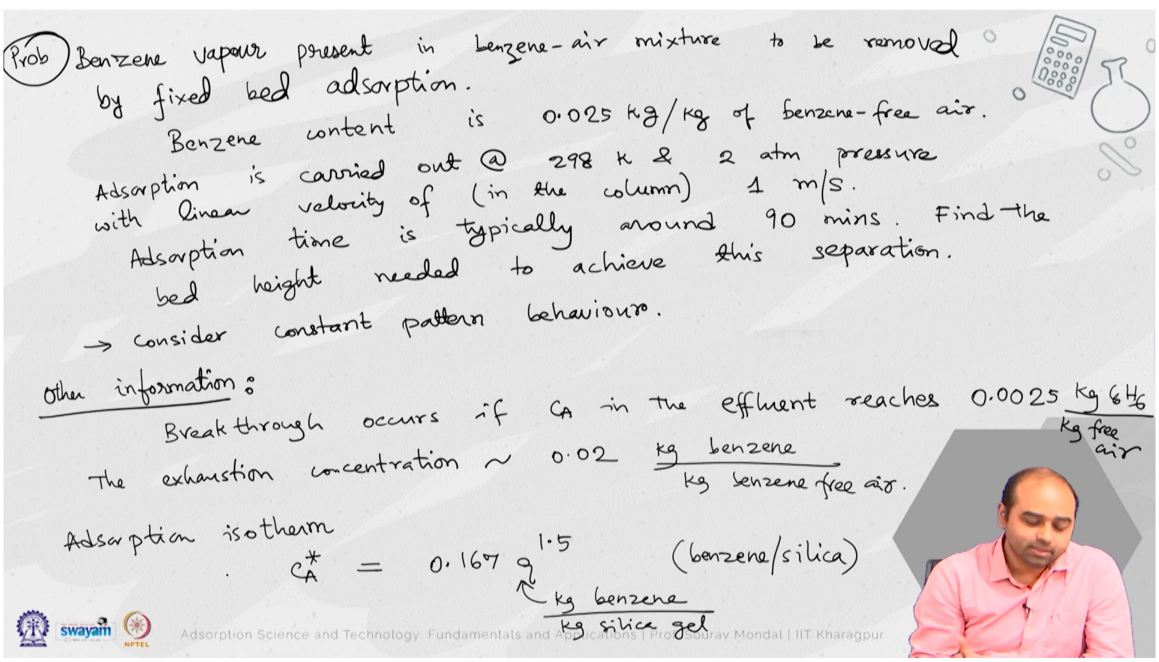
**Week 06**

**Lecture 27 | Fixed Bed Adsorption: Illustrative Problems**

Hello everyone, today we are going to talk about some example problems related to this modeling of fixed bed adsorption column and how essentially we can try to find out you know the size or the dimensions of this column based on certain information that is provided. So, we will mostly try to use this constant pattern behaviour as well as we will see that how you know another problem on how that is useful or can be compared with the results to the Thomas solution or the Thomas method of the solution. So, let me first introduce the problem to you. So, this is a system of stripping or removal of benzene from benzene air mixture. So, benzene vapour is present. So, this is like the problem statement.




The benzene vapour present in benzene air mixture to be removed by fixed bed adsorption. So, the benzene content is 0.025 kg per kg of free air or let us say benzene free air and adsorption is carried out. at 298 Kelvin and 2 atmosphere pressure with this with linear velocity of in the column essentially this linear velocity in the column of 1 meters per second.

This adsorption time is typically around 90 minutes. So, we have to find out the bed height needed for to achieve this separation. So, of course, in the first case of the first part of this problem we consider this to be like constant pattern behaviour. So, now there are some additional. So, this is what the problem statement is.

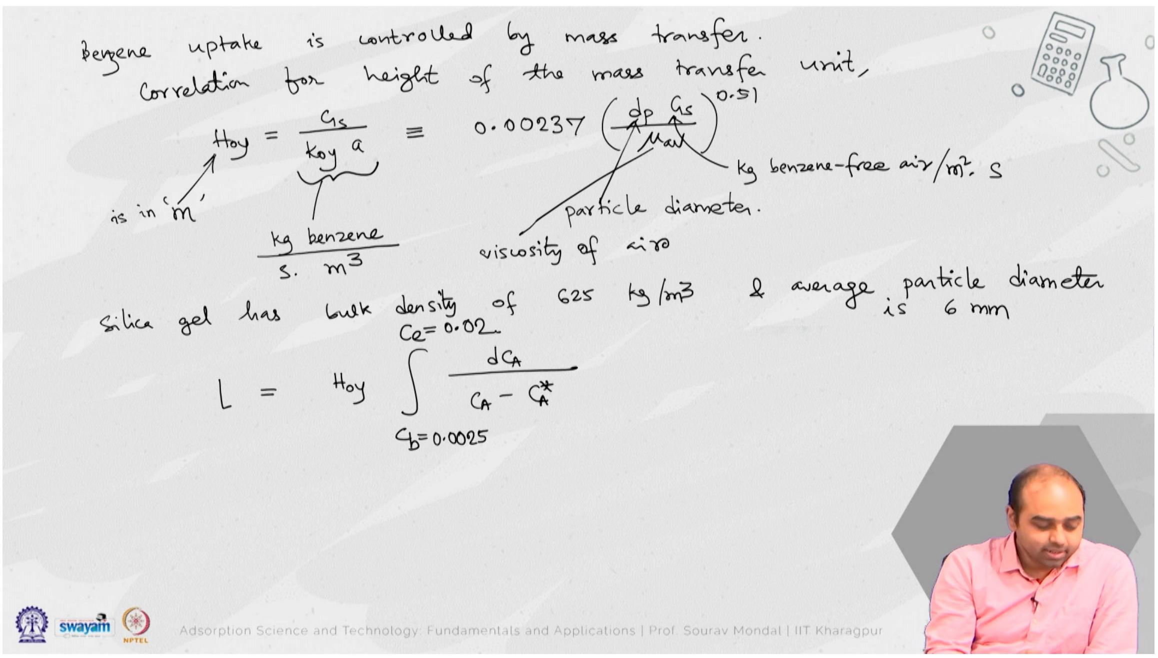
So, this is the problem statement. We have to find out for this operation to remove benzene from this benzene air mixture. What is the height of the bed that is needed and we are assuming it to be or consider it to be constant pattern behaviour. Now, there are some more information. That for the design calculation if this breakthrough occurs if this concentration C of A of the benzene in the output or in the effluent stream reaches around 10 percent of the feed value kg benzene per kg is free air.

The exhaust concentration or the exhaustion concentration. So, the exhaustion concentration determines that more or less when you know there is the bed do not have any long do not possess any more you know adsorption capacity. So, in that case the exhaustion concentration can I mean it can be said that the bed has reached its saturation limit. So, typically the exhaustion concentration could be like 0.

02. Of course, at the typically for a true exhaustion the outlet concentration should be equal to the inflow or the inlet concentration. But in this case we are considering that up to almost you know 80 percent of this value the bed is almost going to be saturated. So, that is what we write. Now, the adsorption isotherm which is very important here. So, this adsorption isotherm is given by this Freundlich you know model C A star is 0.167 Q to the power 1.5. So, this is for benzene silica system where silica is the adsorbent in this case. So, Q as you can understand is essentially the you know this kg of benzene per kg of silica And of course, C A star is essentially the equilibrium concentration of benzene with respect to the kg of benzene per free year. Now, this benzene uptake is controlled by mass transfer.

So, benzene removal benzene uptake is controlled by mass transfer. And in this case, the correlation for height of the mass transfer unit $H_{oy}$ which is given by G by $G_s$ by $K_{oy}$ a is mentioned. I mean this relation is given to you. So, this helps to some extent, where of course G is the G s is the kg of benzene free air per meter square second. So, this is like the you know this superficial gas velocity or the air velocity K_o_y a is the K_o_y a is in kg of benzene per second per meter cube, H_o_y of course, is in meter.

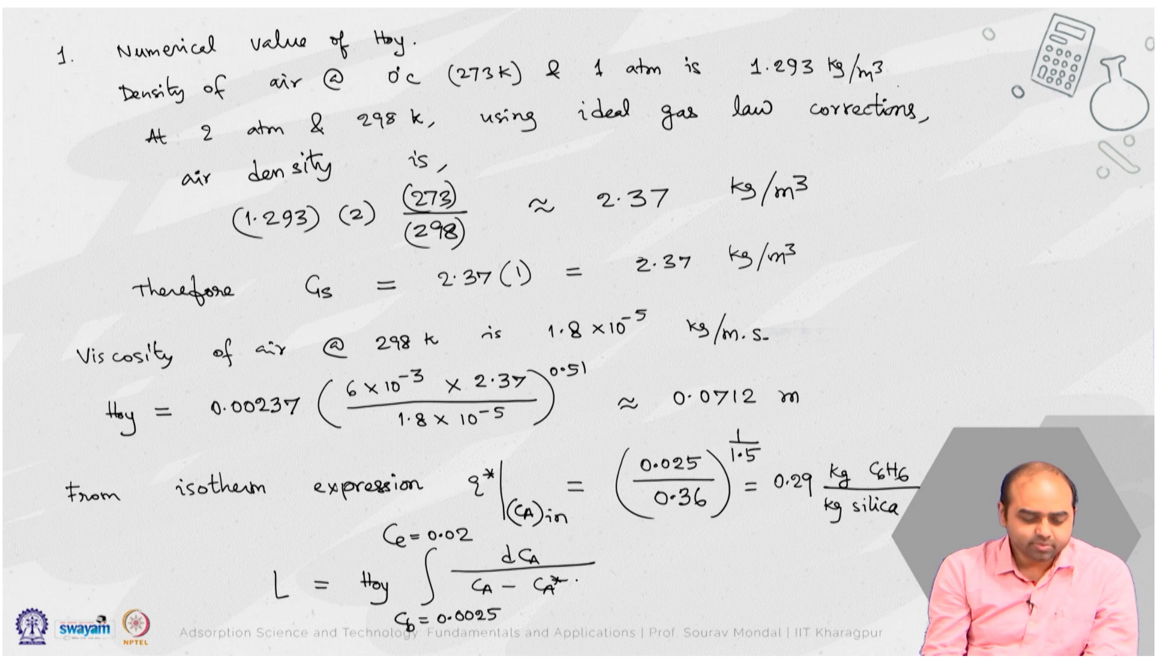
This dp represents the particle diameter or the pellet diameter of the adsorbent and mu Av represents the viscosity of air. So, typically silica gel has a has bulk density of 625 kg per meter cube and average particle diameter is 0.6 or 6 mm. So, these are the additional information which is provided. Now, as you can understand the major task that we need to do is to calculate that integral.




So, the height or the absorption tower height capital Z or let us call it as capital L is like H_o_y and this is the integration that we need to work it out. So, this is like the breakthrough concentration is the exhaustion concentration d C A with respect to C A minus C A star. So, this C A B is actually the breakthrough concentration is 0.0025 and this is like this exhaustion concentration is up to 0.02. So, this integration essentially we have to evaluate. Now to evaluate this you know this information or to use this information we have to take into account some more you know corrections here in terms of H_o_y essentially because h o y is given as a function of the flow rate and everything. So, we have to work out appropriately what would be our H_o_y. Now, please note that this Gs is given in terms of benzene free air, but we know that this benzene free air has to be converted to the benzene and in that case we have to know what is the density of the air appropriately this can be you know adjusted the air. So, the density of air.

So, we are we are going to proceed in that direction. So, first we have to calculate the numerical value of H_o_y. So, the density of air at 0 degree centigrade or 273 Kelvin and 1 atmosphere. is 1.293 kg per meter cube.

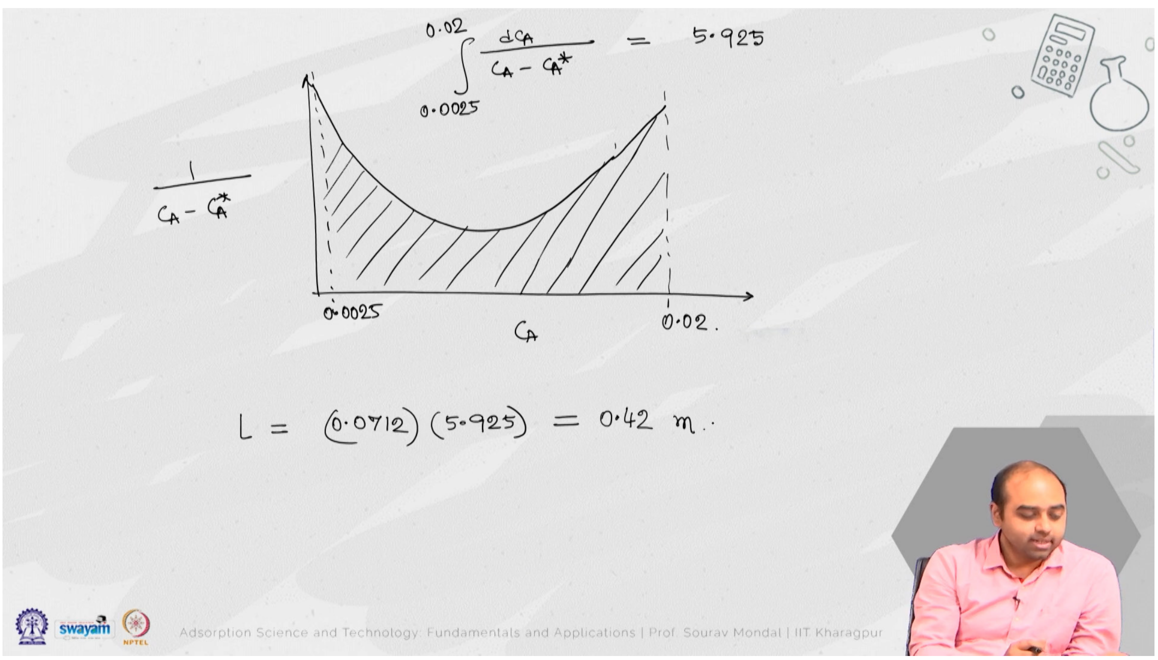
Now, here the operation is the 2 atmosphere pressure. So, at 2 atmosphere pressure and 298 Kelvin. So, you can use ideal gas law. Using ideal gas law correction, air density is sorry 298 Kelvin. So this is the value of G s that we have in this case because originally for this correction that we have to that we are making here is for 2 you know this 2 bar pressure or 2 atmospheric pressure.




So that correction or this value of the G s is very important in this case. So viscosity of air at 298 Kelvin is around this value. So, this H_o_y stands out to be 0.00237 x 6 into 10 to the power 3 that is the particle diameter. Then we have the value of G s divided by the value of the viscosity all in SI units to the power 0.51. So, if you work out the numbers this will come to around 0.0712 meters. So, now it is time to use the isotherm expression.

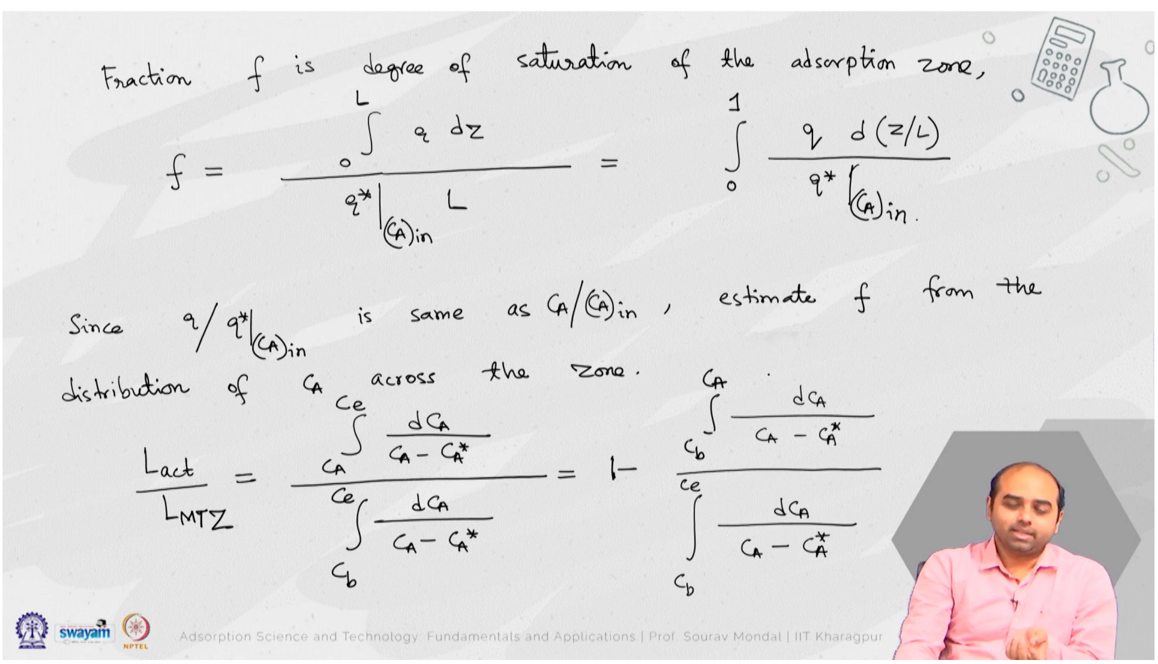
So, from isotherm expression evaluating Q star at Ca in would be equal to 0.1 by 1.5. So, this turns out to be 0.29 kg benzene per kg silica. Now of course, to calculate the length of the this adsorption bed tower we have to evaluate this integration starting from C B which is 0.0025 to C E which is 0.02 this evaluation of this integral. Now, to evaluate this integral as you know we have to find out the values of corresponding values of a C a and C a star over this different range. So, let us say I take a prepare a table of C A, C A star C A minus C A star and then appropriately the value of 1 by C A minus C A star.

So, taking the values starting from the lowest value that is C B 0.0025, we take intervals of every 0.0025 for something like this. all the way up to CE is equal to 0.02. So, we can work out from this relation of what would be the appropriate values of CA star at these corresponding conditions. So, this can be you know it is essentially we are going to prepare this with the help of you know the equilibrium isotherm relations and accordingly this entire chart will be worked out or you know found out or tabulated. So, now, the idea is to work out what would be the area under this curve. So, if you try to prepare a plot of this. So, this integration of this quantity C A minus C A star.

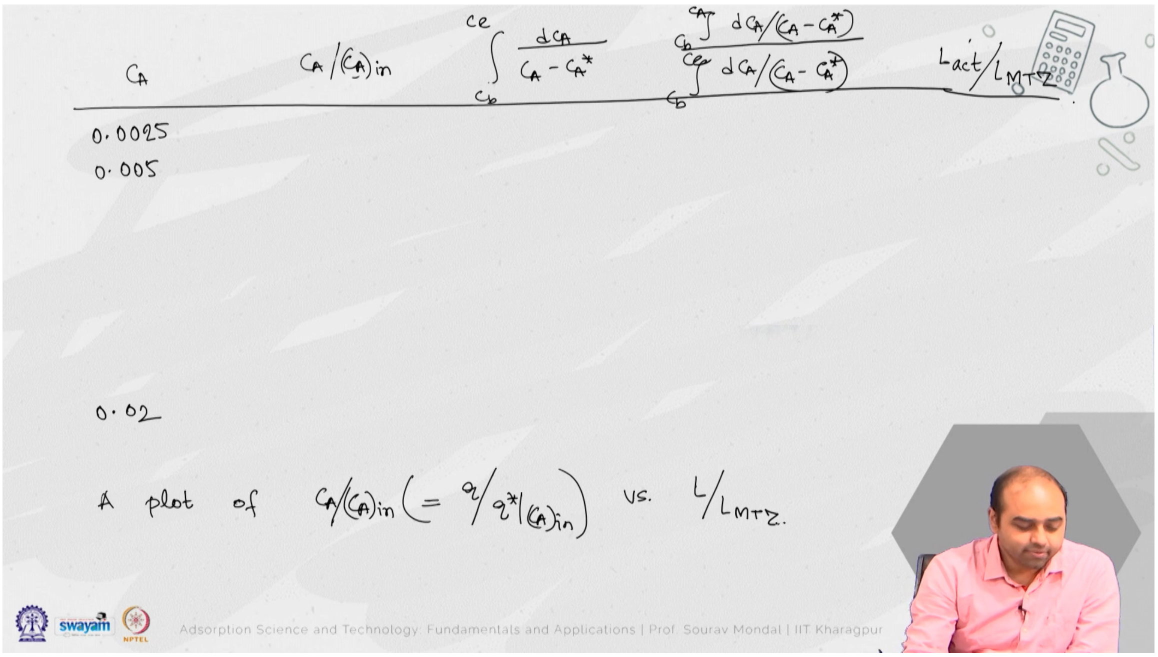



So, if you work out this plot would look something like this ranging from the values of almost from 0.0025 to all the way up to 0.02 within this range the value of 1 by C A minus 1 by C A star will work out like this and if you plot. So, if you and so the idea is that this integration of d CA with respect to CA minus CA star for the values from 1.0025 to 1.02 is nothing but the area under this curve right. So, either this can be found out graphically or you can use any of this numerical you know methods this trapezoidal rule one third trapezoidal rule or this sorry Simpson's one third rule or the trapezoidal rule you can work out and you can see that the area under this curve or this integration value will come out to be around 5.925. Now, once this is known then you can find out this value of this length of the bed that is needed is 0.0712 multiplied with this integration of 5.925 and that comes out to be around. Now, please understand that this is the amount or this is the height of the bed which is needed to have or to you know make this adsorption possible. But it is very important that we also take into account of this fraction of the saturation that is needed within this adsorption zone and accordingly that additional area is also accounted for sorry additional height that is also accounted for within this fixed bed column. So, now coming to this fraction, it is very important to also you know take into factor of this fraction of the saturation of the adsorption zone that is very important. So, taking into account of this fraction then it becomes slightly interesting part. So, please note that here we are using this fraction F is the degree of saturation of this adsorption zone.

So, by f we mean that 0 to L with respect to q star into L. So, in other words, this can be also in terms of written down as d of z by L divided by q star at c a So since q by q star at C A in is same as C by C A by C A in. one can readily estimate f estimate this fraction f from the distribution across this zone. Now, from here the L actual the ratio of this L actual with respect to L can be given as this C A to C E divided by CB to CE. So, it may be noted that this fraction that we are trying to you know take into account here actually relates to the amount of the adsorption that happens within the mass transfer zone and within the zone previous to the saturated portion like the LES.

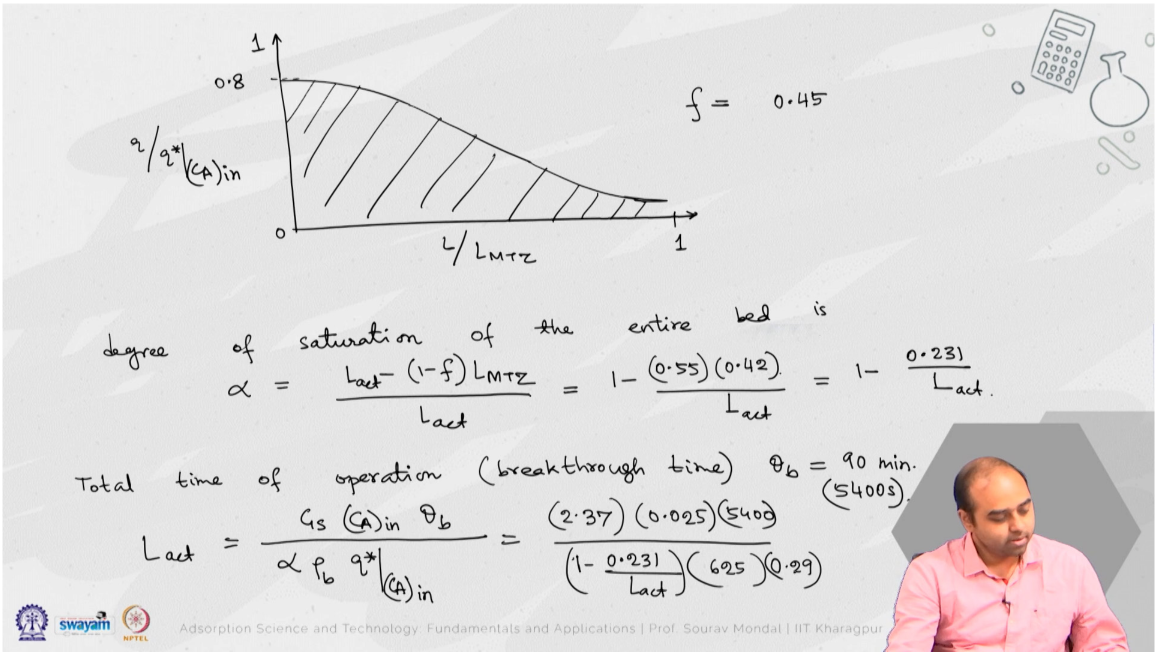



So, this is what the ratio takes into account. So, it is better to say that this L that we have so far calculated actually represents the you know zone of the mass transfer. So, maybe I can write this entire L as this zone of the mass transfer. And the zone of the this particular you know the column is actually is a ratio of this zone of this mass transfer zone with respect to the total height or the total length of this region. So that is how we are taking into account of this two part of the breakthrough curve and that is where the behavior of the constant pattern is actually utilized here.

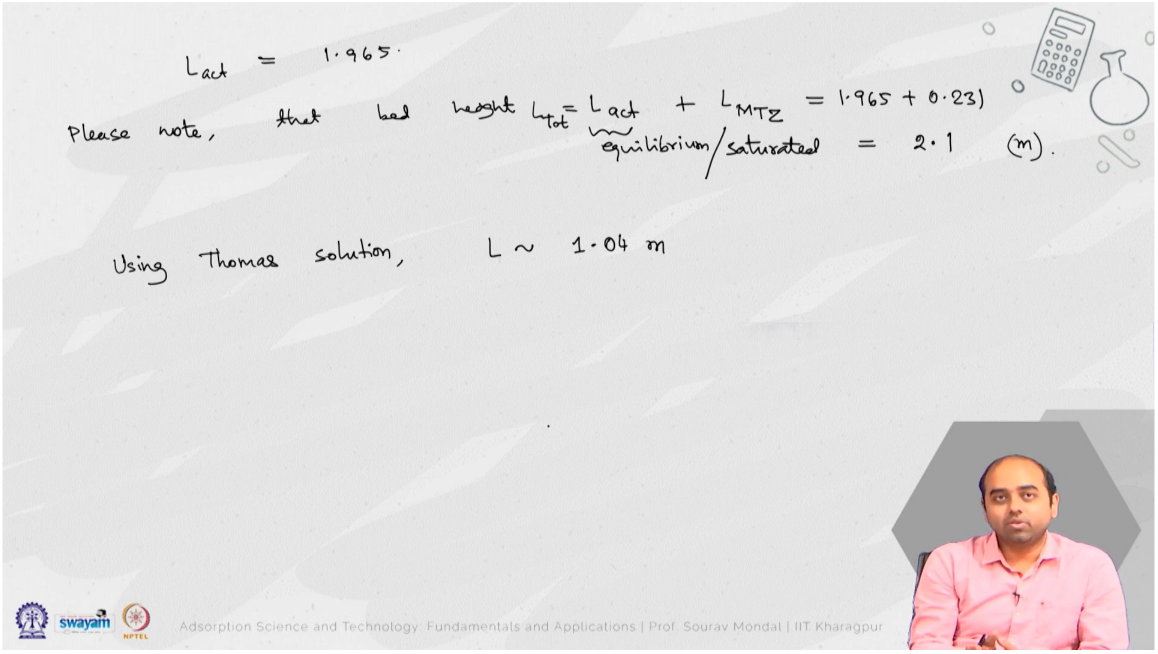



So we have to write this zone as the length of the mass transfer zone. Whatever the f that we have calculated so far is actually the length of the mass transfer zone. So this can be represented by 1 minus Then the numerator we actually segregated this part of CE as like CA plus CB and that is how we could rearrange this integration. So, now with this new ratio we are again going to work out this you know table. where we tabulate the values of this quantity and then the ratio of this quantity d C A by C A minus C A star by the integration again of d CA by CA minus CA star of course, with different limits CB to CA and this is from CB to CE and this is length actual by length of the mass transfer zone. So, this if you we once again do the same exercise for these values. So this is how we are going to prepare this table. Now a plot of C A by C A min which is nothing but equal to Q by U star at C A min. versus this L by L_MTZ is to be worked out and from there you can find out that what would be your value of the F.

So if you try to draw this plot this ratio of L by L_MTZ with respect to q by q star at C A in. This will be a value from 0 to 1 and in this case you will see that this and this will be also from 0 to 1. So, this plot will start somewhere from 0.8 and this will go all the way up to something like this. So, the area under this curve will tell us the value of f.




So, once this f is found out then the degree of saturation. So, in this case the F will be found out is 0.45. So, the degree of saturation of the entire bed is let us call that is alpha as this l minus 1 minus of f this l m t z or whatever this l actual This L actually is given as 1 minus (0.55)*0.42 divided by this L. That is 1 minus 0.231 by L or this L actual. So in this case since total time of operation which is nothing but the breakthrough time let us call it as theta b is 90 minutes or this is equivalent to 5400 seconds. So this actual bed length is Gs into Ca in times theta b multiplied with alpha rho b q star. This is from the you know this total amount or the level of the adsorbent loading if you recall from that relation you can found out how much this from a simple mass balance on the amount of the this you know bed that is saturated so if you work this out this length of the portion of the bed which is in the equilibrium so if you put the numbers So this is the part of the bed which is actually under saturation. So if you work out these numbers, the L that you are going to get is 1.965. Now please note that the bed height is essentially the summation of the this part which is essentially the equilibrium or the saturated zone, or saturated zone of the bed plus the length of the mass transfer zone LMTZ. So, if we add both of this and that part is 0.231, the total height comes to be around around 2.1 meters or so. So, this is what we see from this exercise that how we can work out the total height of the bed considering the you know this ratio of the mass transfer zone to the constant pattern analysis.




Now, the same problem one can also evaluate using Thomas method and I leave it to you as an exercise to work out what would be the height with the help of the Thomas bed Thomas method and in that case you can see that the height of the Thomas bed is actually much less. So, the using Thomas method, using Thomas solution you will see that the L comes out to be almost 1.04 meter almost half of the calculated value that we get from this constant pattern analysis and you need to worry or you need to think that why is it so or what are the assumptions that we have considered within the Thomas solution is it applicable in this case or not. So, I think with this I will close the lecture for today. If you have any confusions regarding the working steps, please feel free to write to us or ask in the open chat forum and that we believe we can help you or assist you more with additional information. Thank you and see you all in the next class.