

Downstream Processing
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Lecture - 15

We will continue with the topic of absorption, and today we will do some more problems. So, that you are completely thorough with the knowledge of absorption.

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A feed of 1.2 ltrs contains $3.9 \cdot 10^{-4}$ mol/ltr of a protein. 80 cc of an adsorbent will adsorb a maximum of $7.8 \cdot 10^{-6}$ mol of protein per cc of the adsorbent. The process follows Langmuir isotherm. The constant in the isotherm (K) = $1.9 \cdot 10^{-5}$. What will be exit concentration

$$q = \frac{q_{\max} \cdot x}{K + x}$$

$$Wq = F(xF - x)$$

$$q = \frac{x \cdot 7.8 \cdot 10^{-6}}{x + 1.9 \cdot 10^{-5}}$$

$$1.2 \cdot (3.9 \cdot 10^{-4} - x) = 80 \cdot q$$


 3.9 $\cdot 10^{-5}$ mol/ltr

Consider a process where the absorption follows a Langmuir isotherm, so if there is a Langmuir isotherm, obviously you need the 2 constants, one is called the maximum absorption that is the q_{\max} which is given here $7.8 \cdot 10^{-6}$. Then, we have the constant that is the constant which comes with the denominator of the equation. So, both are given, now we are adding a feed of 1.2 liters, which contains a protein of certain concentration moles per liter of the protein. Now, you are adding 80 cc of an adsorbent and the goal is to absorb as much of the protein as possible and as I said It follows a Langmuir isotherm.

So, this is a Langmuir isotherm equation q equal to q_{\max} multiplied by x and that is the concentration of the solute, which is in equilibrium with the concentration of solute in the absorbed face divided by k plus x . So, once you write the mass balance and mass consist of as I said before the past three or four class, the material coming in, in the form

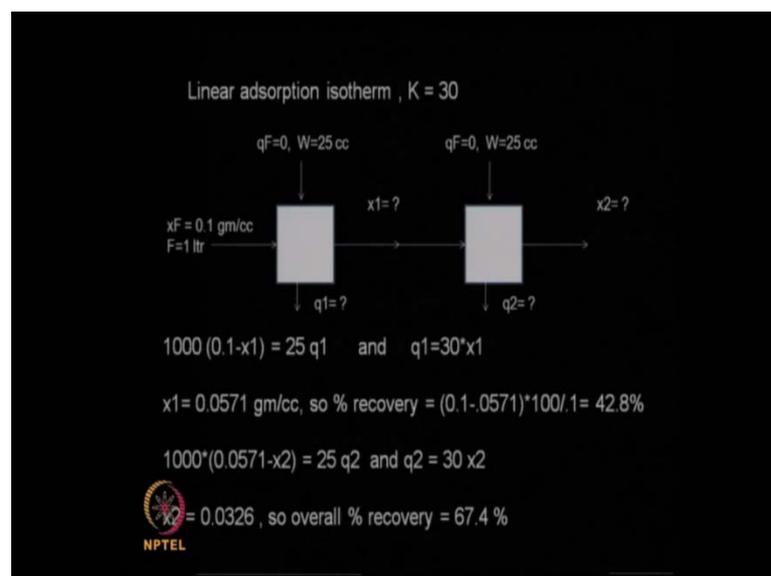
of the solute in the broth and the solute that is absorbed that should be equal to the concentration of the solute in the absorbed face.

So, W into q where W is the amount of absorbent we are taking in that is given here 80 cc, q is a concentration of the absorbent that is been taken up by the absorbent. This should be equal to F , F is the quantity of broth or slurry or solution you add that is 1.2 liters here multiplied by x of minus x . Where, x_F is the concentration of absorbent in the feed and x is the concentration of absorbent after the absorption process that is x_F minus f .

So, you are balancing these 2, where q is given by x into 7.8 into 10 power minus 6 divided by x plus 1.9 into 10 power minus 5 . So, you can balance these equation and you see that x is appearing both in the numerator and the denominator that means, you need to solve it by trial and error. So, it is slightly tricky whether you can do it by graphical method or you can use some computational tools non-linear solution procedure. There are many software, which can help you to do that and thereby you can calculate your x .

So, x comes out to be 3.9 into 10 power minus 5 mols per liter, so you are starting with the about 4 into 10 power minus 4 moles per liter of the protein, which is absorbed using absorbent. The solution finally, contains 3.9 into 10 power minus 5 moles per liter solute.

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Now, let us slightly complicate the absorption process, sometimes it is not possible to complete the absorption in one stage, so you may resort to 2 stages, so like this particular

figure. So, you have stage one, where you have the solution containing the solute is introduced and you are adding a fresh absorbent here, and then after you do the absorption you may remove the absorbent using filtration. Now, you have this mother liquor or the broth its take to a second state, where again you may add some fresh absorbent and again you may repeat the same process. So, this is a 2 stage absorption process or you can have multiple stages you can have 3, 4, 5 and so on.

And here in each stage your adding fresh absorbent that means q_f equal to 0 that means the concentration of the solute absorbed that is introduced is 0 that means, it is a fresh absorbent. So, in this 2 stage process our goal is to find out what is the overall efficiencies of the absorption process. That means we need to do a mass balance here calculate the concentration of solute that is living and then we do a mass balance here. Then, you can calculate the concentration of the solute that is leaving a second stage and by comparing it the initial feed, we can say this is the overall recovery efficiencies or overall absorption efficiencies.

Assume it to be a linear absorption isotherm you can extend it whether its Froude or ((Refer Time: 05:19)) the same approach. So, what is the mass balance here? We have one liter solution. So, we convert that into cc, the feed is 0.1 and what is the concentration of the solute leaving will be unknown x_1 , which is equal to 25 is the quantity absorbent you are adding. Here, we are assuming 25 cc of absorbent and normally you will be adding grams, so you need to know the bulk density. So, that you can convert into volume.

Now, q_1 is the concentration of the solute in the absorbent which is given by the linear isotherm. So, q_1 equal to 30 comes from here x_1 , so we can substitute q_1 this particular term, so and we can solve for x_1 to get that x_1 is equal to 0.0571. So, the percentage recovery will be your reducing it to 0.1 to 0.07, so you just point 1.5071 multiply by 100 divided by 0.1 that comes out to be 42.8 percent efficient. So, this particular stage helps you to absorb 42.8 percent of the solute of interest. Now, let us do the same thing in the second stage.

So, again you have the 1,000 that is your feed 1,000 cc and then the concentration of the solute entering will be 0.571 and the x_2 is the unknown and then your adding same amount of absorbent. You may add different types of absorbent, you have

correspondingly that number here assume in this particular problem like your adding in the first stage. So, again it is a fresh absorbent, so there is no solute already present absorbed on the absorbent. So, again its equal to 25 into q_2 and q_2 is given by 30 into x_2 here. So, you see look at this 2 equations although they all follow the linear absorption isotherm the q_1 and x_1 are related like this and q_2 and x_2 are related like this. So, the equations here are very different.

So, you substitute again here and you can calculate for x_2 say x_2 comes out to be 0.0326. So, if you compare 0.1 and 0.326 we can find out the overall absorption efficiency right that comes out to be 67.4 percent. So, what it means is if I have a single stage absorber and if the system follows a linear absorption isotherm, the efficiency of absorption is 42 percent by adding another absorber I am increasing the efficiency from 42 to 67. So please note that you are not adding 42 to another 42 and getting 80 percent, but actually you are getting only 67 percent. So, if I add third absorber I may add another 10 percent may be if I had forth absorber I may add 5 percent so on.

So, as we keep on adding extra am stages you are not going to dramatically increase the absorption efficiency, but you will be just adding only small amount of improvements. But then why do you add multiple stages? You need to add multiple stages if you are interested to absorb as much of solute as possible, may be the solute which you are absorbing the protein of interest for you. So, you want to recover all the protein so when you do it one absorption stage may be you are not able to recover you will go to next stage, until all the protein is absorbed. So, you resort to this type of approach if the solute is extremely important for you if you want to recover all the solute.

So, you get 67.4 percent efficiency by putting in the second stage. So, you can have a third stage or forth stage and so on. So, in the third stage, what will be the linear absorption isothermal equation it will be q_3 equal to 30 into x_3 . So, in the fourth stage it will be q_4 into 30 into x_4 so that's our assumption that the 30 remains always whether it is $q_1 x_1$, or $q_2 x_2$, or $q_3 x_3$ that 30 will always remain constant. So, that is one of the assumptions when we do this type of multiple stage absorption process remember that. So, that means the constant remains same irrespective of the concentrations because initially the concentration x_1 may be very high, but later on x_2 will be lower than x_1 , x_3 will be lower than x_2 and so on. But still we assume that this constant in the linear absorption isotherm does not vary, generally that is what you assume, but in reality it

may change and it may take different values depending upon the concentration of the solute, which you are trying to absorb.

That means high concentration you may have different constant value at low concentrations you may have different constant value, but in this particular problem we assumed that the constant k in the linear term remains constant, do not forget that. This is called a cross flow system that means, the solution is flowing this way and your adsorbent is flowing vertically so that is called a cross flow system. But let's look at another system this is called a counter current system, that means your solution is flowing like this and your adsorbent is flowing from this way second to 1. Solution is flowing from 1 to 2 and out where as your adsorbent is flowing from 2 to 1 and out this way notice that.

So, if I have three stages what will happen my solution will be flowing from 1 to 3 where as the adsorbent will flowing from 3 to 1. So, this is called a counter current system so let's look at this particular problem in counter current system this is this is slightly tricky. You will notice why it is tricky later actually so let's look at a counter current where the solution is fed here, again its one liter and the solution contains 0.1 gram per cc of the solute concentration.

Now, the concentration of the adsorbent added is 25 cc, but the concentration of the solute on the adsorbent is not zero because it is coming from stage 2 here right. So, it is not zero please remember so it have some number we will call it q_2 , and then it is leaving the stage 1. Now, let's go to stage 2 now whatever solute is left behind from stage 1 absorption enters the stage 2 and there is an absorption taking place here, now here the adsorbent is fresh. So, there is no solute on the adsorbent here so here you can take q_f equal to 0, you see that whereas in a cross flow system, we took hear equal to 0 in both cases because you are adding fresh adsorbent.

Whereas in a counter current system because the adsorbent used in the stage 2 is sent to stage 1 it contains some amount of solute adsorbed. So, here q_f is not equal to 0, but here you are adding a fresh adsorbent that is why q_f equal to 0. So, if we have three stage counter current system, what will happen? The adsorbent is added fresh in the third stage so only there you can assume q_f equal to 0 where as in other stages you cannot assume the concentration of solute that is adsorbed in the adsorbent as 0.

So, this is slightly tricky let us look at stage 1 and do a mass balance so thousand cc actually one liter, what is entering through the solution is 0.1, what is leaving is x_1 so $0.1 - x_1$, this is equal to 25 is the quantity of adsorbent you are adding in terms of the volume. And q_2 is the concentration of the solute entering because of the adsorbent and q_1 is the concentration of the solute leaving the stage with the adsorbent. So, you have $q_1 - q_2$ here right. And of course, q_1 and x_1 are related by the linear absorption isotherm equation $q_1 = 30x_1$.

Remember the linear absorption isotherm or any isotherm will always have the concentrations from the leaving streams, not from the entering streams. So, the assumption in a stage process is the streams that are leaving are in equilibrium, the streams that are leaving are in equilibrium. So, what are the streams leaving here $q_1 = x_1$ correct, so that is why you put q_1 and x_1 we do not put these two terms in this equation we put q_1 and x_1 here. So, we can substitute q_1 like this in to this.

Now, let's look at the second stage so the concentration of the solute entering through solution is x_1 and what is leaving is x_2 . So, thousand into $x_1 - x_2$ will be equal to now here the adsorbent is fresh right. So, there is no concentration of solute entering because of the adsorbent, so that is why we add only one term 25 into q_2 whatever leaving. And again $q_2 = 30x_2$ so you see again as I said the streams that are leaving a stage or an equilibrium. So, $q_2 = 30x_2$ now we can substitute q_2 here and q_1 like this so you end up with 2 simultaneous equation containing 2 unknowns x_1 and x_2 understand. So, 2 simultaneous equation containing x_1 and x_2 so we can solve and we end up with quantity of x_1 is point 0.0756 quantity of x_2 is 0.43. So, from 0.1 we reduce the concentration of the solute to 0.43. So, the efficiency overall efficiency can be calculated it comes to 0.7.

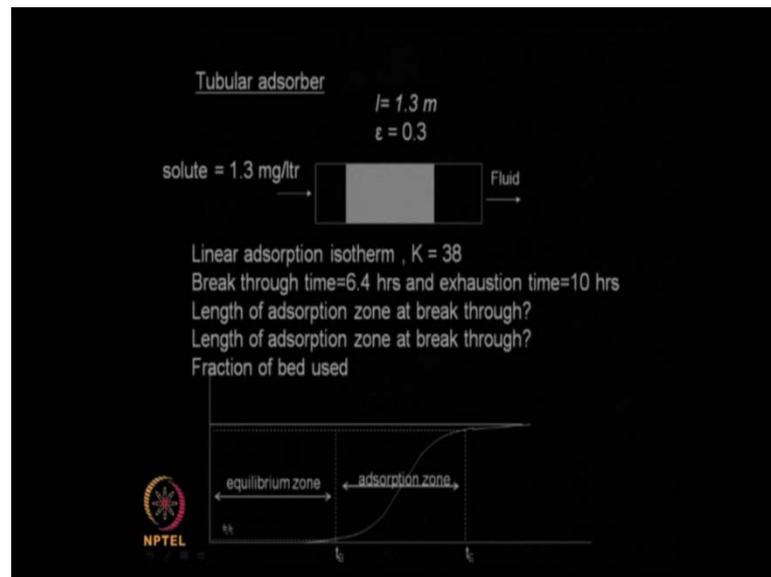
If you notice the percentage efficiency from the previous problem where we used cross flow type of design this is a counter current type of design. So, in the cross in the cross flow I got 67.4 percent recovery whereas, here I get about 56.7, so almost a reduction of ten percent right why is that because in cross flow we are adding fresh adsorbent at each stage, in counter current the absorber and the adsorbent is sent from the second stage to the first stage.

So, only in the second stage you are adding fresh adsorbent, so the efficiency goes down by 10 percent, but the advantage is that you are using the same adsorbent. Whereas in the previous design you are having 25 plus 25, 50 cc of fresh adsorbent so that means you are using up quite a lot of adsorbent if you want to use a cross flow type of study. That means if you are using too much you need to recover recycle and again keep it back otherwise it is not very efficient, you can't throw away the adsorbent and because you are operating cost will be a function of adsorbent. Unless the adsorbent can be just disposed off in the environment without causing any toxic hazard, otherwise if it's an expensive one like zeolites and so on you have to recover.

And here in this design you are using 50 cc for one operation, whereas here you are using only 25 cc which is sent from second stage to first stage. So, the amount of adsorbent you are handling in this counter current design is less. So, economically it will work out cheaper, if you are using very expensive adsorbent. For example, if you are having three stages in a cross flow you may have each stage, if you are adding fresh you will be using up so much of adsorbent. Whereas if you use a counter current type of design you will be using the same amount of adsorbent hence extending it up for all the stages.

Of course, the efficiency goes down as I showed in this particular problem when you use a counter current efficiency of recovery is only 56 where as the other one comes out almost 67. So, efficiency goes down, but the amount of adsorbent you use is less so for very expensive adsorbent a counter current is much more economical.

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Let's go forward let's look at a tubular absorber, as I explained in the previous class tubular absorber contains adsorbent pact in tube of varying length and of dimensions diameter of varying diameter. Now, you have the feed solution or feed gas entering from one end and its leaving form the other end, and the concentration of the solute is 1.3 milligrams per liter. Assume that the system follows linear absorption with a k value that is the constant value of 38 break through happens after 6.4 hours and absorption at 10 hours. You remember the break though curve I hope you all remember the break through curve, initially all the solute gets adsorbed by adsorbent because your adsorbent is very fresh.

So, whatever stream that is leaving here will be devoid of any solute there won't be any adsorbate present here. But as it gets saturated slowly, slowly will start seeing some solute in the exit stream and that is called the break through point that is the point at which you start seeing the solute in the exit stream. And after sometime the adsorbent is completely filled with the adsorbate so it is not doing any job whatever solute concentration that is entering will be exactly leaving that is called the absorption time.

So, here in this problem the break through time is given 6.4 hours and the exhaustion time is given as 10 hours. So, you are asked to calculate the length of the absorption zone length of the... And fraction of bed used. Fraction of the bed used at the breakthrough. Now, let's recall how the break through looks like and what is the absorption zone and

equilibrium zone, this is the break through x axis is your time. So, your graph starts like this and then it goes in a sigmoid ail fashion and it flattens out. So, this is called the break though time and this is called the exhaustion time and this region is called the equilibrium zone and this region is called the absorption zone.

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Tubular adsorber

$l = 1.3 \text{ m}$
 $\epsilon = 0.3$

solute = 1.3 mg/ltr → Fluid →

Linear adsorption isotherm, $K = 38$
Break through time = 6.4 hrs and exhaustion time = 10 hrs
Length of adsorption zone at break through?
Length of adsorption zone at break through?
Fraction of bed used

Adsorption zone = $1.3 \cdot (10 - 6.4) / 6.4 = 0.73$
Equilibrium zone = $1.3 - 0.73 = 0.57 \text{ m}$
Fraction of bed used = $1 - \Delta t / 2t_b = 0.72$

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So, absorption zone how do you calculate that the solute concentration is 1.3 mg per liter the length is also 1.3 meters. So, length of the column 10 is your exhaustion time 6.4 is the break through time divided by the break through time that is 0.73. I hope you remember this equations which we did couple of classes back so the absorption zone can be calculated as length into delta t divided by the t b where t b is the break through time so delta t is nothing but difference between the exhaustion time and the break through time.

So, 10 minus 6.4 divided by 6.4 multiplied by 1.3 gives you 0.73 that means 0.73 meters is called the absorption zone and then equilibrium zone you can subtract from the overall length that comes out to be 0.75 meters. So, 0.57 meters corresponds to the equilibrium zone and 0.73 meters corresponds to the absorption zone. So, what is a fraction of the bed used at the break through? Again if you remember I taught you couple of classes back its given by the formulae 1 minus delta t divided by 2 t b, delta t is the exhaustion time minus the break though time.

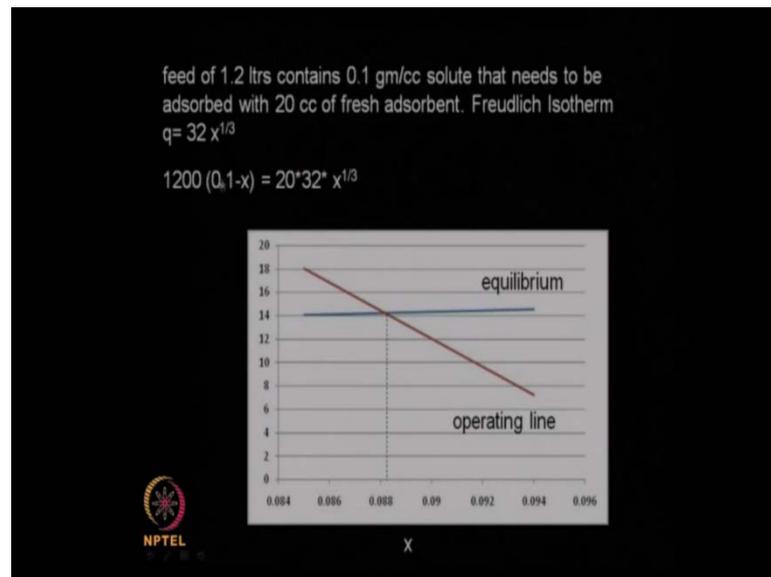
So, if you substitute this terms you get 0.72 that means 72 percent of the bed is used up when the break through happens. That means 28 percent of the bed is not used up and when the break through happens why is break through very important because as soon as the break through happens you dint want to continue the absorption because some of the solute will start coming out in the affluent. So, you would like to stop the absorption process and regenerate your bed, and then again bring it back into operation. So, whenever you stop the absorption process you are loosing time ideally is should have the fraction of the bed used during break through closer to 1.

That means I will be if I use more of the bed for the absorption better it is if it is less bed I need to keep on regenerating quite often. And as I said if I want to regenerate I will be stopping my bed, I will be passing some gas or using high temperature to regenerate my adsorbent. So, I will be spending money on the operating cost, so more the best used up when the break through happens better it is, that is why this particular calculation is very very important. Fraction of the bed used during at the break through point and here in this particular problem we find out that 72 percent of the bed is used up, when the break through happens.

That means 28 percent of the bed is not used up, but still you will stop the absorption process and regenerate your material. Whereas if you get less number like instead of 72 percent you get 50 percent then its highly inefficient because the remaining 50 percent of the bed is unused and as soon as 50 percent gets used up we will stop your absorption process and regenerate. So, if such a situation arises what do you do you need to find different adsorbent which is much more in efficient.

So, you need to select adsorbent so that the fraction of the bed used up keeps going up and up comes closer to one and higher the number better it is 0.8, 0.85 then the number is very good. Whereas 0.7, 0.6, 0.5 definitely it's not very good.

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Let's look at another problem we have a feed solution of 1.2 liters and it contains 0.1 gram per cc of the solute, the solute is what we would like to adsorb with 20 cc of fresh adsorbent. And this absorption process follows a Freundlich isotherm and the isotherm is given by q equal to $32 x$ raise to the power of $1/3$, where x the concentration of the solute in the solution equilibrium with the adsorbent again we can do a mass balance. So, how do you do that we can do 1.2 liters that is 1200 cc, the amount of solute is 0.1 and the amount of solute after the absorption process is x . So, $0.1 - x$ now this should be equal to the amount of solute that is present in the adsorbent.

Initially the adsorbent is fresh so you can just put 20 cc multiplied by 32 into x to the power $1/3$, now see if you want to calculate x it becomes trial error process so we can not directly calculate so we, but we can still do a trial and error, assume different values of x and see whether you are able to solve it. And of course, there are many software's available now a days which can also do it, but a very easy approach is possible that is using a graphical method. So, let's look at the graphical method this portion I had told you before is called the operating line, this portion.

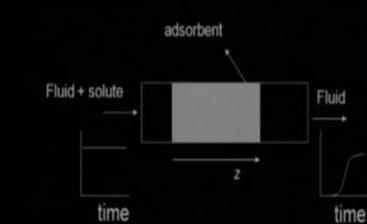
So, for different values of x on the x axis if I substitute here I can get this number $1200 \cdot (0.1 - x)$ so it will look like this and it will be going down sloping down because we have minus x here this is called the operating line, this portion is called the equilibrium, this portion $32 x$ raise to the power $1/3$ here putting 20. So, this portion relates to the

equilibrium here so for different values of x I can plot 2 curves the operating line corresponding to this line and the equilibrium curve corresponding to this side. So, if you plot them both in a graph sheet and where ever they intersect that will be the value of x , very simple. By using a graph sheet I do not need to use a software package to find out the value of x and I plot this portion as function of x which will appear like this, and the point where they intersect will be the value of x very simple.

So, using a graph sheet we can immediately calculate x without resorting to any computational or a numerical technique. Otherwise we can use x 1 and assume different values of x and then by trail and error calculate and what will be the actual value of x by solving this. So, when x 1 can be used to the this type of and solution, but most of the absorptions study if you have a graph sheet you can do it very simply. And before the advent of computers people used graph sheets to solve equations of this type, and if you a equation like Lanmer where you have coming x in the numerator x coming in the denominator. Again you can resort to a graph sheet to solve it right.

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Tubular adsorber



$$\varepsilon \frac{dx}{dt} = -v \frac{dx}{dz} + D_d \frac{\partial^2 x}{\partial z^2} - (1 - \varepsilon) \frac{\partial q}{\partial t}$$

ε = void fraction in the bed, $v (=F/A)$ = superficial velocity, A = cross sectional area of the pipe,
 D_d = dispersion coefficient

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Let's further look at the another problem, in the tubular observer we sometime back talked about here slightly more accurate approach to calculate the concentration both as a function of the distance z d z of a function of time. As the fluid flows there is going to be absorption taking place as the solute gets absorbed, the concentration of the solute is going to vary as a function of the length of the tube and it also vary as a function of time.

That is why have equation which has rate of change of concentration as a function of time, and we also have change in the concentration as a function of z. And I also mention that this term comes because of the diffusion, where D is the diffusion coefficient this term comes because of the bulk moment of the fluid through the column and this term comes because of the absorption of the solute from the liquid phase to the solid or the absorbent phase. We can try to simplify this equation by assuming certain things.

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Tubular adsorber

$$\varepsilon \frac{dx}{dt} = -v \frac{dx}{dz} + D_a \frac{\partial^2 x}{\partial z^2} - (1 - \varepsilon) \frac{\partial q}{\partial t}$$

Due to flow

Accumulation=0 Axial Dispersion/Diffusion=0 Transferred to the solid phase

$q = K x^*$
 $r_{ads} = k_l a (x - x^*)$

Linear adsorption isotherm
 Axial dispersion is negligible
 No variations in solute concentration in the liquid phase

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Suppose we assume accumulation is 0. That means the accumulation of the solute in the liquid phase 0 because the amount of liquid present in the valve itself is 0, amount of solute present in the valve is 0, then we get neglect this portion. If we assume that the diffusion of the dispersion is very, very little we can neglect this equation. So, we are we can easily neglect these two equations, if we assume here linear absorption isotherm then q equal to k x star and rate of absorption is equal to k l, k l is the mass transfer coefficient a is the interfacial area multiplied by x and x star.

So, we can instead of x star substitute this x minus k, so we will end up a linear differential equation, we can reduce the second order partial differential equation is equal to linear differential equation.

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$$v \frac{dx}{dz} = k_1 a (x - q/K)$$
$$dq/dt = k_2 a (x - q/K) / (1-\epsilon)$$
$$t=0, \text{ all } z, q=0$$
$$t > 0, \text{ at } z=0, x=x_F$$

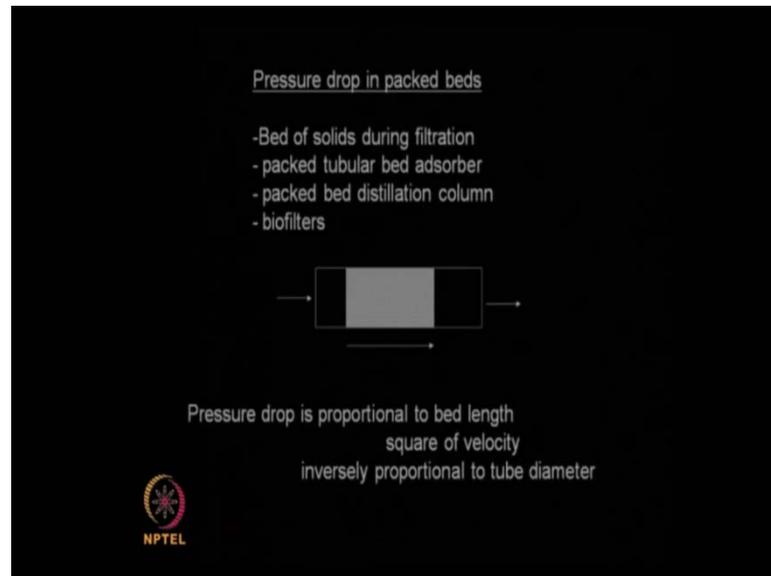

Like this $v \frac{dx}{dz}$ is equal to $k_1 a (x - q/K)$ and $\frac{dq}{dt}$ is equal to $k_2 a (x - q/K) / (1-\epsilon)$. So, x will be a function of z and t . Of course because concentration of x changes along the length of the axis as well as a function of time. And similarly, q also will vary length of the column and time it needs a initial conditions and at t equal to 0, at all locations along the axis is q equal to 0 because nothing has been observed at t greater than 0, the fluid entering so at z is equal to 0 x will be x_f that is the maximum amount of absorbate present at the entrance of the tube.

We can solve these using these conditions the initial conditions this is called and this is called the boundary condition because this is at the entrance so that is called the boundary conditions. Just like sure tank absorber if you recall couple of classes back we did the stir tank absorber, where we had linear adsorbent isotherm, we developed a relationship between x that is the concentration of the solute in the stream going out of the stir tank absorber as a function of time. And similarly, we developed another equation that is the concentration of solute in the adsorbent in the function of time.

Whereas in a tubular design not only time comes in the z also comes in because the concentration of solute along the axis of bed will also vary that is why you have z also coming into the picture, that is the main difference between here the tubular design and stir tank design. In stir tank everything is stirred so we have a bulk concentration. Whereas in tubular we do not have back mixing that is why the concentration of the

solute along the z axis also will vary in addition to solute concentration varying as a function of time. So, here stir tank has complete back mixing where as tubular has no back mixing.

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Now, you also have to consider the pressure drops because when you have a pack bed and when a solution flows through it, whether it is a gas or a liquid when a fluid flows through it because the fluid can flow only through the interosseous is the packing material prefers resistance and so there is always a pressure developed. So, the feed that is entering the pack bed has to overcome this particular pressure. So, either it is achieved by having a pumps so that the pump can deliver a enough pressure for the fluid to pass through it and come out from the other side.

Especially if the packing is very, very long or if you have small particles then pressure drop will be very high. Now, this pressure drop arises in many systems we especially in filtration as the solid keep settling on top of the filter the liquid has to flow through the bed so there is a pressure drop coming into the picture. So, initially there won't be any solid bed formed on top of the filter medium, but as time progresses the bed is formed. So, the liquid has flow through the bed and come outs on the other side, so you need to have enough pressure for the pressure to flow through.

Absorber like we have seen a part bed tubular absorber you need to apply enough pressure so that the liquid can overcome the pressure drop and comes the other side.

Pack bed distillation column where you are distilling a mixture of liquids into various factors and if you have the column as a packed bed then again the pressure drop will be tremendous. And you need to have the vapor way to overcome this particular pressure drop.

Bio filters where you are trying to remove toxic gases using a packed bed of micro organisms and nutrients, then again you have an situation of pressure drop. So, in all these areas you need to consider the pressure drop and the inlet pressure should be sufficiently large enough to overcome this pressure drop. Now, pressure is proportional to many terms like bed length, if the bed length is very large then your pressure drop is going to be also very large. Velocity it will be the function of velocity so if the velocity is large pressure drop is large velocity is low pressure drop is low. Inversely proportional to tube diameter if the tube diameter is very large pressure diameter is less if the tube diameter is very less pressure drop is high. So, small tubes will encounter higher pressure drops large diameter tubes the pressure drop is less.

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Bed length =20 cm, diameter=2.5 cm, bed volume = 70 cc, Pressure drop = 2 bar

Bed length =?, diameter=25 cm, bed volume = 70,000 cc, Pressure drop = ? bar

Bed volume = $(3.141 \cdot \text{dia}^2 / 4) \cdot \text{length}$

Volume increased 1000 times and dia increased 10 times -
length to be increased 10 times

So over all pressure drop will increase 10 times , ie=20 bar

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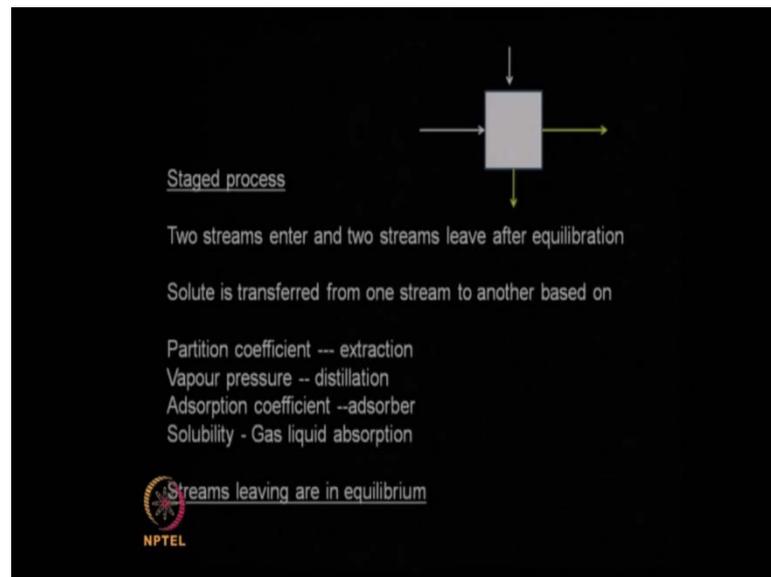
Now, let's look at a problem imagine I have a pack bed length is 20 centimeter diameter 2.5 centimeter bed volume is 70 cc. So, it's got a pressure drop of 2 bar that means if this first side is atmospheric pressure I need to introduce my fluid at least at pressure of 2 bar so that it can travel and cum out on the other side. Now, I want to increase my increase my bed volume thousand times means seventy thousand cc, I want to increase diameter

10 times that is 25 centimeter. Now, the question I need to answer is what will be the pressure drop of this particular new pack bed when compared to old bed. So, the old pack bed, bed volume of 70 cc diameter of the tube was 2.5 centimeter the new pack bed has a diameter of 25 centimeter it is got a bed volume of seventy thousand cc, what is the pressure drop? The pressure drop of small set up was 2 bar pressure bar of large set up I need to calculate.

Now, you know bed volume how do you calculate πd^2 by 4 into length agreed. Now, the volume has increased thousand times and the diameter is increased ten times. That means the length will increase ten times right because diameter is increased ten times. That means diameter square that is hundred length has increased to ten times. So, the diameter is increased to ten times, the length has also has increased to ten times. So, the bed volume is thousand times diameter is ten times bed volume and diameter related by diameter square. So, this will become hundred times, so obviously the length will go by ten times. So, the length has gone up by ten times that means pressure drop will go up by factor of ten, but my diameter also has increased by ten times that means the pressure drop will go down by a factor of hundred right square because of the diameter my pressure drop will go down by hundred, because of the length pressure drop will increase by ten times.

So, over all the pressure drop will increase ten times that means it will become 20 bar. So, the current pressure drop of this particular will be ten times the pressure drop of the previous unit.

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Now, we have been talking for some time on something very, very important that is called stage process or a stage process. That means we assume an absorption taking place in a single stage, we have the feed solution containing the solute we have the absorbent added here either in the form of fresh absorbent or already containing some absorbate and then two streams are leaving. One is the feed solution which has now lost some solute because of the absorption process and the absorbent has collected some of the absorbate. So, two streams are entering two streams are leaving in a stage right after equilibrium and this particular stream, and this particular stream that are leaving are considered to be in equilibrium. And this called a stage process.

In a stage process solute is transferred from one stream to another, so in absorption what happens the solute is transferred from the liquid to the solid, but in the these option you can have the other way the solute can be transferred from the solid to the liquid that is the desorption. But something is happening you have many streams mixing there is an equilibrium taking place and the streams are leaving, that is what is called staged process. And stage process exist in many areas of downstream and unit operations. For example, if you put extractor or extraction process you have the solvent and you have the heavy liquid the solvent and the heavy liquid are mixed together, and the solute is extracted by the solvent correct. So, that is a stage process.

Distillation you have vapor and liquid and the light material or low boiling materials goes to the vapor phase, heavy boiling material goes to the liquid phase again staged. Absorber we just saw so the solute from the liquid phase goes to the absorbent phase or in a desorption the solute from the solid phase comes to the liquid phase, that is a stage process. Gas liquid absorption where you have gas soluble into bulk liquid like carbon dioxide in mono ethanol amine chlorine and sodium hydroxide and so on. So, recovery of many gases are performed in a gas liquid absorption process and they are all based on solubility and again this is also a stage process.

So, chemical engineers have being very comfortable with this type of concept of stage process. So, an adsorption, absorption, distillation extraction they are called stage process and you can have multiple stage process or single stage. So, the whole process can be carried out in one stage where you put in the two streams together mix it thoroughly and allow it to equilibrate separate and the two streams leave. So, the whole thing can be done in one stage or you can do it in multiple stages, that means you allow it to separate then you add some other stream and again mix it allow it to separate, then go to third stream stage and so on. So, you can have multiple stages.

So, thing happen in each stage there is an equilibrium that will take place in each stage. So, stage 1 equilibrium is very different from stage 2 equilibrium which will be very different from stage 3 equilibrium and so on actually. So, the assumption in this type of operation is that there is an equilibrium, which takes place between the streams that are leaving the stage and the equilibrium that is reached in stage 1 will be very different from the equilibrium that is reached in stage 2, stage 3, stage 4 and so on. But they all follow the same principle so for example, like I explained linear absorption isotherm if stage 1 follows linear absorption, we can always assume that stage 2, stage 3, stage 4 everywhere you may have the same isotherm same constant values.

So, if you assume extraction taking place in stage 1 and the partition coefficient value is given in stage 1, we can assume that in each other stages also same partition coefficient value. So, it make the life slightly easier, but the main assumption in a stage process is that the streams that are leaving are a equilibrium and the type of processes that staking place in each stage is similar. So, by doing this we can sort of rationalize many operations unit operation, we can also extend knowledge from one type of unit operation in to another type of unit operation. You will see that especially when we go to the next

topic of extraction you will see very interesting mass balance and other calculation, which will look like almost similar to what we studied in absorption. When we go to distillation you will see the same concepts coming into picture.

So, we can extend the various concepts you have learnt in one area of unit operation into another area and so on. That is the main advantage of grouping systems as stage process. Another advantage of stage process suppose I have a tubular reactor I for a tubular absorber, we talked about it few slides back. You need to have partial differential equation because there is going to be variation in concentration across the length, as well as a function of time.

Now, suppose I break the tubular reactor into many stages hundred stages for example, for thousand stages and each stage I assume it as a mixed store tank vessel. Then the calculations the type of equation become simpler because in single stage like I talked about in a batch process, it is just material input equal to material output there is no differential equation coming into the picture. For each stage I can write a simple algebraic mass balance equation and I can solve it. So, instead of having differential equations by doing this type of multiple stages, we can approximate a tubular reaction or a tubular absorbed we can simplify our calculations understand instead of having differential equations, we are going to have many mass balance algebraic equations, representing each of the stages. And it becomes much easier for us to solve algebraic equations rather than solving partial differential equations.

Number 2 each of the stage process will have certain constant describing the principle under which it works, like in a extraction you have something called partition coefficient, which is almost similar to your linear absorption isotherm. So, you have a two streams connected by a constant called k similarly, in extraction you may have a two streams connected by a partition coefficient. So, the constants will appear to be almost similar when you move form an extraction to an absorption or to a gas liquid absorption or to a distillation. So, these are the advantages of a rationalizing the various equilibrium process as a stage process. And when we go to extraction or when we go to distillation we will see how useful this type of knowledge is all about.

Thank you.