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# Lecture - 14 Adsorption (Continued)

We will continue with the topic of Adsorption, it the adsorption can be done either in a batch mode or in a continuous mode. So, if it is a batch mode what you do is you take your adsorbent you mix it up thoroughly with the broth, the fermentation broth or the solution containing the solute or the adsorbate that needs to be recovered, mix them thoroughly and then you filter it out. So, your absorbate or the solute would have been adsorbed in the adsorbent.

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So, the concentration of the solute, would have gone down in the feed and some amount of solute would have been taken up by the adsorbent. So, there are two streams entering the particular stage of batch process and there are two streams leaving the same stage. So, one stream relates to the solution or the broth which contains the solute or the absorbate, the other stream contains your adsorbent, generally the adsorbent will not have any solute; that means, the adsorbent may be very fresh, so you will not have any solute. So, in that particular case the concentration of the solute or the adsorbate will be 0. Now there will be two streams that will be leaving this particular stage, one stream is your a broth, which will have a reduced amount of the salute or the adsorbate. And the other one is your a solid adsorbent, which would have taken up quite a lot of the solute.

So, we need to do a mass balance of this particular stage, so the amount of a solute entering in stream as well as the out stream, the amount of solute leaving in this particular stream as well as in this particular stream. So, you need to just balance these four terms that will give you a mass balance for the solute, which is given by this. So, like I explained in the previous class, we have a x F is the concentration of the solute or the absorbate, F is your feed solution. And similarly, you have x that is the concentration of the solute or adsorbate leaving and F again is your feed solution.

We will assume that there is no change in the amount of the feed solution and then similarly you are adding a adsorbent of a quantity W, had been certain concentration of the solute already adsorbed on the adsorbent. But, generally if you are taking a fresh adsorbent q F will be 0 and on the right hand side, we have again another term this is the amount of a adsorbent leaving the stage; and this is the concentration of the solute or the adsorbate that has been taken up by the adsorbent.

So, we have these four term and this called the operating line. So, we can use this particular line for many purposes, we can use it to calculate the amount of adsorbent required, if I want to achieve certain efficiency that mean I want to recover 90 percent of a protein, how much of a adsorbent I need to add. Or on the contrary, I may say that I have certain amount of adsorbent mixed with the broth, what will be the percentage recovery, so I can use it for that type of calculation also; now I also mentioned that a you have something called the isotherm.

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There are 3 types of isotherms which we talked about the linear isotherms, the freundlich isotherm and the langmuir isotherm. So, if you look at the isotherm for a linear and the x axis has your x, x is the concentration of the solute or the adsorbate in the broth and the q is the concentration of the same solute in the adsorbent. The x and q or in equilibrium they can form different types of equilibrium either a linear relation or freundlich or a langmuir. So, in the case of a linear you are going to have a relation like this, and a the operating line which contains terms like a the amount of a slurry, the amount of a broth you are adding, the quantity of adsorbent you are adding, the concentration of a you are solute in the slurry or in the broth and the concentration of the solute that is leaving.

So, this is the equilibrium line which I talked about in the previous slide. So, the equilibrium line will generally look like this. So, this is your isotherm relationship this is given as q equal to k x. So, where ever it is cutting, that will be the value of x for a given set of F W and q F and x F. So, graphically also we can solve this particularly equation and the linear equation, to get what will be the concentration of the solute or the adsorbate, after the adsorption process understand.

So, that is for the case of linear isotherm, suppose I have a freundlich isotherm you know the isotherm looks like this. We mentioned it about couple of class back, if you recall and again the operating line is going to be in the same way. The operating line is this particular relation and where ever they are cutting is where determines the concentration of your solute in the slurry at the end of the adsorption process and the concentration of the solute, in the adsorbent at the end of the process.

So, graphically also all I have to do is I draw the freundlich isotherm, I draw the equilibrium line and I will see where it cuts, if I want to solve it numerically again it is like two equations are there I can substitute them and then I can use them. Now, let us go to the third term isotherm that is the langmuir isotherm, as you recall langmuir isotherm looks like this right, x axis is x and y axis is q, langmuir isotherm assumes a monolayer adsorption.

So, after sometime the number of sites available for adsorption is 0, that means all the sites are blocked. So, whatever be your extra concentration of the solute in the slurry, the quantity of q is not going to increase, so it will flatten out and once again it will have an operating line. So, this is where the, you can determine what will be the value of x and q, using this particular graphical method. And again if you recall the Langmuir isotherm equation is q equal to k into x, divided by some another constant plus x.

So, Langmuir isotherm will have two constants, linear isotherm will have one constant and freundlich isotherm will have two constants, because there will be an exponent term also; again we talked about it a 2 classes back. So, you need to check from your old notes to see the equation for linear, freundlich and Langmuir isotherm.

So, this is one way of solving these two equations in a graphical way, you draw the operating line, which is a straight line it will be sloping downwards and then you draw your isotherm, depending upon. Whether it is linear or freundlich or langmuir and then see where they cut that will give you the solutions for these two equation that will give you what will be the value of x and q, we will look at some problems later on in the end of the class or in the next class.

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Now, let us go to continuous stir tank again I just introduced this concept, so adsorption can be done either in a batch mode or in the continuous mode. So, if you look at a continuous stir tank, what is happening you have the adsorbent inside like a solid material, like your activated carbon or a zeolite beads or a silica gel beads and so, on. And there is a agitator here and continuously you are feeding in the solution, which contains your solute or the adsorbate, the solute gets adsorbed and the stream that is leaving will have less amount of the solute.

So, x will be less than x F, V is the concentration of the tank, one important point if you are operating a continuous stir tank adsorber is you should see that a the adsorbent does not escape through the exit stream, so there might be a c or a filter or a strainer put in, so that these particles do not escape all. But, then a as time goes if attrition takes place; that means, if the particles become powdery they may start escaping and start going downstream.

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So, how do you develop a model for this type of continuous adsorbent, t looks slightly complicated, but it is not complicated. So, again you have to do a mass balance solute in, minus solute out, minus solute adsorbed, is equal to accumulation. Solute in this is the solute in, F is the flow rate of this slurry or the broth or the medium, which contains your solute or the adsorbate at a concentration of x F.

So, F into x F gives you the solute in, F into x gives you the solute out, so this is the quantity flowing out, this is the concentration of the solute in the exit stream. So, this is in, this is out minus amount adsorbed, so because solute from the solution phase goes to the adsorbed phase. So, it is leaving this phase, do not forget that is why you have a minus term here, epsilon is a void age factor; that means, amount of voids. So, 1 minus epsilon gives you amount of solids and V is your volume of the vessel and r adsorbed is a rate of adsorption. So, this term represents the rate of adsorption of the solute from the liquid phase to the solid phase.

So, this is solute into the react vessels adsorber, solute out of the adsorber, this is the amount adsorbed, that means amount leaving the solution phase, moving to the solid phase, this is equal to accumulation, that is why you have d x by d t, t is the time. So, this is the accumulation of the solute inside the vessel, after a longtime when all the solid adsorbed is saturated with the liquid depend any accumulation at all remember, but

initially as these solids get adsorbed on to your adsorbent you are going to have accumulation taking place in the vessel part.

So, this is a typical mass balance type of a equation this is called an unsteady state equation, it is not a steady state, it is an unsteady state equation, because it has not still reached steady state. Steady state, means with respect to time all the parameters are equal to 0 that is a steady state. Unsteady state means the parameters are still varying with respect to time that is why on left hand side you have d x by d t. So, this is an unsteady state mass balance equation and this is an ordinary differential equation.

So, this is an ordinary differential equations and d x by d t, so it is a first order differential equation. Now your r adsorbed can be a liner could be non-liner, so it can be a liner differential equation or it can be non-liner differential. Suppose I if it contains a lanugumuir type of isotherm, then you will have x in the numerator and denominator, if you recall. Whereas, if it is a liner then a you will just q equal to k x, so then it this becomes a liner ordinary first order differential equation. Now, how do you solve this you can solve it a either analytically, if the differential equation is easy to be solved analytically, then we can get mathematical relation between your time and x.

That means, how the x varies with time or q varies with time, but if it becomes very complicated we may not be able to do it analytically, then we may have to use some numerical techniques like a matlab or mathematical or some other software to solve the differential equation, that is a numerical approach. Actually we will take a very simple case and we will try to see whether we can solve this, now there is another important point you need to consider that is the rate of adsorption.

Now, the solute is in the liquid phase, that means, the adsorbate is in the liquid phase, now it has to go to the solid phase. So, you have a liquid, solid inter phase, so there has to be a mass transfer taking place of the solute, the solute has to move from the liquid to the solid phase. So, all chemical engineers know that when there is a phase inter phase between a solid and a liquid or a solid and a gas or a liquid and a gas, then there is something called a mass transfer, so that is what term is going to happen.

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So, there has to be a diffusion of your solute from the liquid phase going to your solid phase and that rate is given by the driving force, that is the concentration driving force, x is the concentration of the solute in the liquid phase; x star is the concentration in the solution which will be in equilibrium with the adsorbent, because ultimately the solute is in equilibrium in the solid phase and in the liquid phase.

Because, it is an isotherm that is the x minus x star is a driving force, k L is called the mass transfer coefficient, a is the interfacial area, that is the interfacial area between the liquid and the solid. So, if a is very large your rate of adsorption is also going to be very large, if a is very small then rate of adsorption will be small.

Similarly driving force x minus x star is large rate of adsorption will be very large, k L is the mass transfer coefficient we can calculate doing experiments, there are many experiments available and chemical engineering techniques are available which can help you to calculate k L. Now, how do you calculate x star, is as I said concentration of solute in the solution which with would be in equilibrium with the adsorbent, this is nothing but, the adsorption isotherm.

So, x star and q will have a mathematical relation can be a liner relation that is liner isotherm. It could be a freundlich type of relation or it could be a langmuir relation, we will take a liner case. So, if we take a liner adsorption isotherm then q will be equal to K x star. So, instead of x star which is an unknown we can substitute as q by K, so the

differential equation will have d x by d t and all the terms will be respect to x and q. And similarly we can develop another differential equation for d q by d t that is the concentration of the solute in the adsorbed phase.

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Just like a this equation will be able to get d q by d t and the amount of a adsorbate on the adsorbent, is happening because of the adsorption only, because you are not introducing any solids in the feed or no solids are leaving the affluent, but solids are present only inside that. So, for d q by d t you will have only this term present you will not have inlet feed or outlet feed for q please remember that. (Refer Slide Time: 17:30)



So, you will have a liner model if you assume a liner adsorption isotherm and a there are many simple techniques are there, which can help you to get an analytical solution.

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So, you can solve them and a you end up with the an equation of this type, this equation for examples shows q, q means the concentration of the solute in the adsorbed phase, that means, on the adsorbent as a function of t. You can see t here and t here and a there is an exponential term.

So, this particular mathematical relation tells you how the concentration of the solute, in the adsorbent will vary as a function of time and there are many parameters that are coming in here; like the flow rate of your feed solution, the volume of you are tank the void age, epsilon k l the mass transfer coefficient, a the interfacial area, k the equilibrium liner adsorption isotherm equilibrium constant.

So, all these come into the picture someway here into b and into sigma and so on. So, the it looks very complicated, but a once you know how to solve a set of liner ordinary differential equations you will understand, why you get this type of equation it is not very difficult. But, we will not spend time in actually solving it, how does this graphs look like as a function of time.

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So, your q will slowly build up, because imagine that initially you do not have any solute adsorbed on the adsorbent. So, q will be 0, but as a function of time slowly, slowly the solute gets adsorbed and finally, it will reach a saturation correct. So, it will reach a plateau now let us look at how the x F minus x vary that means x F is your concentration of solute in the feed, x is the concentration of the solute leaving the fluent, so x F minus x.

So, initially at time equal to 0, x will be 0, then slowly it will reach a shape this form and again this also will flatten out. So, after sometime the adsorbent does not have any capacity to absorb the solute that is why you can see it flattens out it is not going down,

down, down further, because the number of sites available will sort of a reach a is fixed. So, the amount adsorbed is also fixed.



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Now, we looked at a batch process, then we looked at a stirred tank continuous process, let us look at stirred tank not a stirred tank, but let us look at a tubular continuous process that means, you have a long tube and the adsorbent, that is the solid is packed inside the tube. A long tube and your adsorbent is packed and the fluid with the solute flows in as it travels, the solute gets adsorbed and the fluid is leaving with less of the solute present. So, you can have very long column you can have a very short columns, depending upon the efficiency of adsorption as well as the capacity of the adsorbent to absorb the solute.

So, with time what happens is I will have a certain concentration of the solute inside the fluid and if you see the exits stream, when you have a fresh adsorbent all the solute would have got adsorbed right. After sometime the solute will be, so much that the entire adsorbent would have got adsorbed this solute and there will be some solute will be leaving this particular tube, that means, the adsorbent would have got saturated with the solute and it will not be able to absorb anymore.

So, what happens initially you will not find any solute, because it would have got totally adsorbed and because the adsorbent is fresh and after sometime what happens, you will start seeing some solute coming out of the fluid in the exit fluid. And then finally, the adsorbent is totally saturated with the solute, that is not going to be anymore adsorption, so whatever is coming in will start going out.

So, you will get a sigmoidal type of curve, initially the concentration will be 0 and after sometime it will start coming out, we will talk about this particular curve more in detail. So, initially your adsorbent is fresh, so it will absorb all the solute, so the fluid that is leaving will be free of any solute, but after sometime slowly, slowly the tube adsorber is getting saturated.

So, you will start seeing some solute in the exits stream or in the affluent stream and finally, after sometime there will not be any adsorption taking place, whatever is coming in will be going out. And this particular curve is also called a break through curve, because after sometime there is going to be a break through happening and your solute will start coming out here.

So, how do you model this particular tubular adsorption process, here it is bit complicated why because, you have the concentration of solute varying across the length of the tube. Suppose we called this z, so there is going to be some dx by dz happening also that means, concentration of the solute varying with distance and you will have concentration varying with time also.

So, you will end up with the partial differential equation, whereas if it is a stir tank adsorber you are having an ordinary differential equation. Whereas in this particular case you are going to have a partial differential equation, that is why you have terms likes d x by d z, that is rate of change of x as a function of z; and you also have d x by d t that is rate of change of x as a function of time. So, you get a quiet a complicated equation and I will spend some time on each one of the term.

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Suppose you take a small section of a your tubular adsorber, so you are you are going to have a the fluid entering here, fluid leaving here and the solute is also entering solute is also leaving, solute is getting absorbed in the adsorber by the adsorbent and a this is of cross section a. So, the velocity will be equal to flow rate divided by a here and there is also going to be some void age; that means, void fraction in the bed. So, 1 minus epsilon will tell you the fraction of the solids or the adsorbent.

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So, having said that let us again go back to the same a equation, which describes the adsorption process in a tubular adsorber; d x by d t as I talked about in the stir tank adsorber is the accumulation term, d x by d z comes because of the flow, because a there is a flow of solution through the tube. So, the concentration moves along the distance of the tube, so you have a term which is because of the flow and then you also have a term which arises because of diffusion. So, the solute is also diffusing in apart from flowing in it is also diffusing in. So, you have a term called a capital D, d square x by d square z, this term represents the diffusion process or the diffusion coefficient.

So, D is diffusion coefficient of the solute in that solution, so you can have solutes which will be highly diffusing or you can have solutes which will be slowly diffusing. So, the diffusion coefficients will depend upon similar several parameters, the size of the solute, the mass of the solute, the viscosity of the fluid, the temperature and so on actually; there are many relationships mathematical relationships which can be used to calculate the diffusion coefficient d. The gases have certain diffusion coefficients, proteins have diffusion coefficient, salts have diffusion coefficient, small molecules and metabolites have diffusion coefficients. And they depend upon the medium through, which it is flowing highly viscous medium diffusion will be very poor.

So, this term represents the diffusion, this term represents the flow or the bulk movement and this term represents the adsorption of the solute to the adsorbent, just like in your continuous stir tank if you remember, we had a negative term. So, this term represents the flow, this term represents diffusion, this term represents the movement of the solute or the adsorbate from the continuous phase or your solution to the solid phase. And all these are equated and on the left hand side we have the accumulation.

So, please recall your stir tank system and a tubular system, in a stirred tank system we had accumulation equal to material entering, minus material leaving minus material or the solute transferred from the liquid phase to the solid phase. So, here we are having accumulation on the left hand side and then movement of the solute, because of the flow and movement because of diffusion and the transfer of the solute from the liquid to the solid phase.

So, this is called a partial differential equation, because we have both a variation of z as well as t, so this is called a partial differential equation. So, it is not very easy for us to

solve this type of equation generally these types of equations can be solved numerically very easily with using certain numerical packages and it becomes quiet commercial. So, we can do using certain assumptions and using certain assumption, we can get certain relationships for the break through curve.



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As I said initially you have a bed containing fresh adsorebent, so the feed is entering with the solute, so the bed is fresh, so whatever solute or the adsorbate present will get completely adsorbed. So, the stream that is leaving the tube will not contain any adsorbate or the solute, so it will not contain any adsorbate. So, the exit concentration of the solute x will be 0 for some time, suddenly after sometime slowly, slowly you will see some concentration, because your adsorbent is saturating.

So, as it gets saturated the concentration of the solute will start rising in the exit stream and finally, the adsorbent is completely saturated with the adsorbate. So, there is no adsorption taking place, so whatever is entering will be leaving correct, so this is called a break through curve and this is called the break through time; that is the time at which you start seeing some solute concentration in the exit stream, so this is called the break through time and this is called the exhaustion time.

So, this is represented by t subscript e, this is represented by t subscript b, that is the break through time and this is called the break through concentration. So, we can say concentration of 1 percent can be assigned as a break through concentration, then we can

say what is the time at which you start seeing 1 percent of the feed in the exit stream. So, if this is your feed if it is 1 percent it may be here, what is the time at which you start seeing 1 percent of the feed in the exit stream that can be fixed as a break through time. You do not need to keep it as 1 percent you may keep at 2 percent or you may keep it at point 5 percent.

So, that is left to you to keep it, so based on your x b that is the break through concentration, you will know at what time this particular break through is going to happen. So, this is a very important a information, because if your operating a tubular adsorber, so as soon as the break through happens you do not want to continue your adsorption, because the adsorption is going to be now inefficient.

So, you will stop your adsorption process you will regenerate, that means you will again freshen up the adsorbent, that means, whatever material has been adsorbed will be desorbed and a once it is again available for the adsorption you may again go back and use it. So, most of the tubular design contains two tubes, one will be performing the adsorption process whereas, other one will be getting regenerated.

So, once the first one is fully saturated or there is a break through you stop the a fluid flow through that particular tube and then you switch over to the second tube and then the first tube you start regenerating. And we talked about the various methods for regenerating you are a adsorbent we can use a high temperature or we can use acids or we can use some oxidation type of approach or even reduction type of a processes all these will help you to regenerate your adsorbent and then it will be ready to perform certain adsorption. So, you need to know how long can I run my column, so that it reaches the break through, so that is a very important design operating procedure.

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So, if you look at this breakthrough, so it is happening at certain time you start seeing some concentration of the fluid in the exit stream this is called the equilibrium zone and this is called the adsorption zone. And mainly from z equal to 0, going right up to z equal to 1 into 1 minus delta t by t B is a your equilibrium zone, where delta t is t E by t B and the adsorption zone, is given by 1 into delta t by t B; that means, delta t is t E by t B where 1 is your bed length.

So, these two zones are given by these two relationship the equilibrium zone is 1 into 1 minus delta t by t B and the adsorption zone is 1 into delta t by t B. So, basically you would like to have a very, very short adsorption zone and you would like to have very long equilibrium zone, that means, the equilibrium zone is very large, I can absorb more of the solute using the same amount of adsorbent. So, you would like a graph like this quickly rising up you do not like a graph, where it is rising up very, very slowly understand.

So, you would rather have a graph which quickly rises up and; that means, the adsorption zone is very, very short, equilibrium zone is very, very large. Whereas if you have a very large adsorption zone and a very short equilibrium zone then that particular adsorbent is not very efficient. So, if the adsorbtion zone is very large that means, your picture will look like this slowly rising and going; whereas you want to quickly have it risen here and you want to have a very long equilibrium zone.

So, how do you find out all these suppose I have in my lab small column packed with the adsorbent, then I pass my fluid with the solute or the adsorbate and then I find out the break through time and the exhaustion time. So, I find out the break through time and the exhaustion time and then using this particular relationship I can calculate what is my equilibrium zone and what is my adsorption zone right very simple. So, you need to collect data in you lab using a tubular adsorbent.

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Again you can use a this for a several other calculations, most important is the fraction of the bed that is loaded. When the break through happens because, as I said once the break through happens you do not want to continue with the same tubular adsorber you want to stop the adsorption you want to regenerate your tube. So, how much fraction of the bed is loaded, when the break through happens more the fraction, that means more efficient, less the fraction that means, it is less efficient you understand. So, I want to have very high fraction that means, closer to one rather than a very low fraction when the break through happens.

So, these are some of the relationships which you make use of one is the q at equilibrium is given by q into x F and the adsorption zone contains half that much, because we assume that this area, this particular rectangular area is divided almost approximately by half by this relation, so we can take this is equal to this. So, or this into 2 will be equal to this, so these are some approximations which we can make use of by doing all these we

end up with the fraction of the bed which is loaded when the break through happens theta is equal to 1 minus delta t divided by 2 B delta t is nothing but, t minus t B, t B is your break through time, t is your exhaustion time.

So, once you calculate the exhaustion time and the break through time in your small lab adsorber you can calculate theta and see how large theta is it closer to 1, 0.855 than it is very good, but if you have less like 0.5. That means, only 50 percent of the bed is fully loaded when the break through happens, that means, other 50 percent is not serving purpose and again after break through you do not want to run the adsoreber.

So, you need to regenerate that means, after every 50 percent a loading you are regenerating your adsorber, which is not very efficient, theta. Whereas if a the theta is 0.85 that means, after 85 percent of loading you are regenerating your adsorber which is good that is why you want to have your theta to be fairly large, almost 0.85. So, if it is small than obviously, that particular adsorbent is not very efficient you need to change your adsorber. So, instead of using a very complicated partial differential equation which we showed coupled of slides back which contains diffusion coefficient which contains d square x by d z square and d x by d t and so on.

The whole process can be simplified based on the break through. So, by just looking at the break through time and the exhaustion time we can calculate the fraction of the bed which is loaded when the break through happens, which is given by this relation theta equal to 1 minus delta t by 2 t B. Where delta t is t E minus t B we can tell how efficient is your adsorbent in a tubular design and if it is not very efficient we may plan to replace it with some other adsorbent. We will again look at some problems a during the course of this particular downstream process.

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So, in commercial downstream process of protein for example, if I want to purify a protein, after the may be fermentation you may have a cell debris, cell and the protein. And we cannot directly go to a chromatograph because, it becomes very inefficient chromatograph may get de-natured or a becomes inefficient because of presence of, so many unwanted material. Sometimes centrifugation or filtration may be very expensive in very large scale and if you know that target protein and you know what type of adsorbent that can be used for a adsorbing this proteins than that process becomes very, very efficient. So, adsorption can be resorted to in such situation.

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Sometimes, we can use a stir tank adsorber like I showed about or we can even use fluidized bed adsorber just like a packed bed adsorber we can use fluidized bed; that means, the adsorbent is in a very fluid state it is in motion, when you put in very high velocities or flow rate then you can have the entire adsorbent in a fluidized state. But 1 main disadvantage in this type of a fluidized bed or pact bed adsorption is that there is a poor adsorption efficiency, because the solids are stationary, the continuous phase the liquid is moving.

So, the adsorption efficiency is very low a leading too low productivity, because of mass transfer effects actually. So, what do you have to do we may have to recycle the feed stream, so we do the adsorption once and then take the affluent again put it back in the feed. So, we may have to do it 2 or 3 or many times, so that you get a complete recovery of the protein of interest for you.

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There is another concept which is called the expanded bed, just like packed bed you can also have an expanded bed is almost like an intermediate to fluidized bed. Whereas, in fluidized bed the entire solid material is in a very turbulent in a fluid state whereas, in a packed bed the solid adsorbent is totally packed and there is no motion. So, basically you achieve the expanded bed based on modifying the flow rate, so the bed gets slowly expanded, so that mixing is better the adsorption that is taking place is also more efficient here. So, there is now more interest in this particular type of a prose that is called the expanded bed.

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So, how do you make this particular expanded bed you will have very large heavier adsorbent beads, at the bottom and then you put in medium type beads later and then finally, at the top you will have very small beads. So, by doing this you are increasing the stability of the bed and you are also preventing undesired circulation of these beads, otherwise these beads will start coming out and start moving with the fluid which is not a very desirable.

So, ordinary resins which are used in a packed bed are not very good for expanded bed adsorption. We need to select the adsorbent, so that you can get almost 100 percent bed expansion; that means, if the original stationary bed is say 10 liters you by expanding the bed you may be able to achieve almost 20 liters of a expanded bed. So, you need to put in a proper adsorbent into these types of bed actually.

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It is used in many applications cell wall hydrolyses you will have cationic proteins, it can be purified using this type of expanded bed. So, here you can use a cationic exchange resin for doing this particular operation actually and it has been also used in many literature examples for purifying hen egg lysozyme, equine milk lysozyme and so on. So, this technique has been found to be very useful for purification.

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Let us look at a now some problems on a adsorption, we have talked about quiet lot of theory we talked about a different types of a adsorbents, we talked about the thermo dynamics of the adsorption process, we talked about the different types of isotherms. We talked about different operations like a batch, like a stir tank, like a tubular packed bed adsorption process. We also looked at the mass balance equations for all this process. So, let us look at a problem.

So, I have batch system. I need to find out how much of adsorbent I need to add, that means, how much of W I need to add. The bulk a solution contains 0.1 milligram per liter of the solute and I want to adsorb 90 percent of this, using fresh adsorbent and the isotherm is a linear isotherm. So, linear adsorption isotherm, that means q equal to K x where K is given by, this a particular term 1 into 10 power minus 5.

The bulk solution quantity is given 1.2 liters, I am suppose to find out how much of adsorbent I need to add to recover 90 percent, starting from 0.1 milligram per liter. When the system follows a linear adsorption isotherm, now units of q will generally be amount of adsorbent on certain grams or milligrams of the adsorbent. Whereas, the units of x please remember will be like milligram per liter of the solution, because x relates to the concentration of the adsorbate or the solute in solution, whereas q relates to the amount of adsorbate or solute adsorbed per gram or milligram of the adsorbent.

So, the units are different. So, please see this milligrams per liter, milligrams per gram. So, the units of K will also be correspondingly like that, you know in this particular case it will take care of gram per liter. It will become grams per liter, because q will be in milligrams per gram, the x will be milligrams per liter, so K will be gram. So, the units of K should match with the units of x and the units of q. (Refer Slide Time: 47:35)

x = 0.1 \* 0.1 mg/ltr =0.01 (F \* F + qF \* W = x \* F + q \*W 0.1 \* 1.2 + 0 = 0.01 \* 1.2 + q \*W  $q = K^* x$ q = 1.0 10<sup>-5</sup> \* 0.01 0.1 \* 1.2 = 0.01 \* 1.2 + 1.0 10<sup>-5</sup> \* 0.01 \*W 0.12-0.012 = 1.0 10-3 \* W W = 108 mg

Now, we take the regular mass balance equation, you have a solute coming in because of the bulk solution you have the solute coming in from the adsorbent. In this particular case, it is given as 0, but you can have situations where the adsorbent may contain some solute you have two streams going out 1 is the solution, which will be containing. Now less of the solute and you will have the adsorbent, which will have more of the solute, so there will be 4 terms, term 1, term 2, term 3, term 4.

Now the concentration of the adsorbate in the final solution will be 10 percent, because you want to adsorb 90 percent agreed and your initials feed contains 0.1. So, 0.1 into 0.1 is 0.01, that will be the concentration of the solute in the exit stream. Now this is your mass balance x F into F, that is the quantity of the solute in the feed x into F, that is the quantity of the solute in the exit or the affluent stream q F into W. Where W is the amount of adsorbent you are adding this is the quantity of the solute coming from the adsorbent. q into W. Q is your concentration of the solute in the adsorbent, so this the quantity of the solute leaving with the adsorbent and because q F is 0 you are adding fresh adsorbent.

So, this will become 0 then a you take a 0.1 is your feed you are taking 1.2 liters of the solution. So, you have 1 2 liters here 1.2 liters here x is 0.01, q and x are related like this, q equal to K x. K is given and q you can take it here, is equal to K into x, is equal to point 0 1. So, you can substitute this particular term here entire this all, so you do not

know is W, that is the quantity of adsorbent required to adsorb 90 percent of the solute in a speed

So, that gives you 100 and 8 milligram as W, so W is equal to 100 and 8 milligrams; that means, if I take 108 milligrams of a adsorbent and I add to a solution of 1.2 liters which contains 0.1 milligrams per liter of a the solute of interest 90 percent of this will get adsorbed. Assuming a linear adsorption isotherm with the K value of 1 into 10 power minus 5 understand. So, you see if I want to perform this adsorption in my lab, a by doing this particular mass balance and assuming I want to recover 90 percent of the solute. I can calculate what should be the amount of my adsorbent required.

So, instead of blindly adding certain amount of adsorbent, I will know exactly if the system follows a linear relationship that I need to add 108 milligrams of this particular adsorbent, assuming it follows a linear relationship. So, depending upon the relationship I may have a different types of equation if it is a freudlish, I may have a x raise to the power n or if I have a Langmuir, I may have a very complicated equation. So, this is a linear relationship, so I just introduced that into my original mass balance and I calculate by W.

Thank you.