Downstream Processing
Prof. Mukesh Doble
Department of Biotechnology
Indian Institute of Technology, Madras

Lecture - 17
Liquid-Liquid Extraction (Continued)

We will continue with the liquid extraction in liquid liquid extraction, you are trying to recover a solute from a fermentation broth or from a reaction medium after a bio transformation using a solvent. As I mentioned the solvent could be a heavy solvent or it could be a light solvent this is one of the best process for biological molecules like bio-molecules because you operate at room temperature and ambient conditions. So, the molecule does not get deactivated or denatured during this process there are two important principals.

In liquid liquid extraction one is the thermodynamics other is the mass transfer mass transfer determines the rate at which the solute moves from the heavies or the fermentation broth into the solvent layer. So, if the mass transfer rate is very high the movement of the solute is very fast so we can achieve the extraction very fast if the mass transfer rate is very slow, then the extraction efficiency is very slow. So, there are different ways of improving the mass transfer rate from the heavy to the light phase one of the approaches is to improve the agitation. That means you create turbulence so that the mass transfer rate is very high, you create very fine particles so that the amount of surface area per volume is also very large.

So, the solute can get transferred from the heavy phase to the light phase so mass transfer is very important in determining the time it take for performing the extraction. Next one is the thermodynamics determines how much can be extracted that means the maximum under ideal conditions what will be the maximum amount of solute that can be extracted from the fermentation into the solvent layer. So, this particular parameter is based on the partition coefficient or it is also called the standard a chemical potential, so it determines based on the standard chemical potential or the partition coefficient for the particular system under consideration.

So, if the partition coefficient is very large then your extraction amount also will be considerable. That means the quantity of the solute that is present in the solvent has

against the quantity that is present in the fermentation broth after they have come into contact. It reaches an equilibrium will be very large liquid liquid extraction is also a stage process just like any other stage process like adsorption absorption distillation chromatography. They are all called stage processes that means there is a stage two streams come and meat they interact and then they reach an equilibrium or steady state and then two streams leave.

So, a solute or a metabolite or a protein or a biomolecule gets transferred from one stream to another stream, it could be because of the vapor pressure reasons because of the solubility reasons because of the partitioning because of the adsorption coefficient. So, because of so many other physicochemical principals it may be moving from one stream to another stream, that is why this is also called a stage process. So, as you can see from this picture you have two streams entering the feed which contains your solute of interest it is also called heavies and it is coming out the fermentation process.

The solvent is your extracting medium solvent could be chloroform dichloromethane ethyl acetate sometimes even we use water and so many other alcohols organic alcohols. Then, once the extraction is done the extract contains most of your solute and the raffinate contains minimum amount of solute and these two streams are in equilibrium at the end of the process. That is why it is called a stage process and it is also called equilibrium process and the ratio of the concentration in the extract the raffinate is what is called your partition coefficient.

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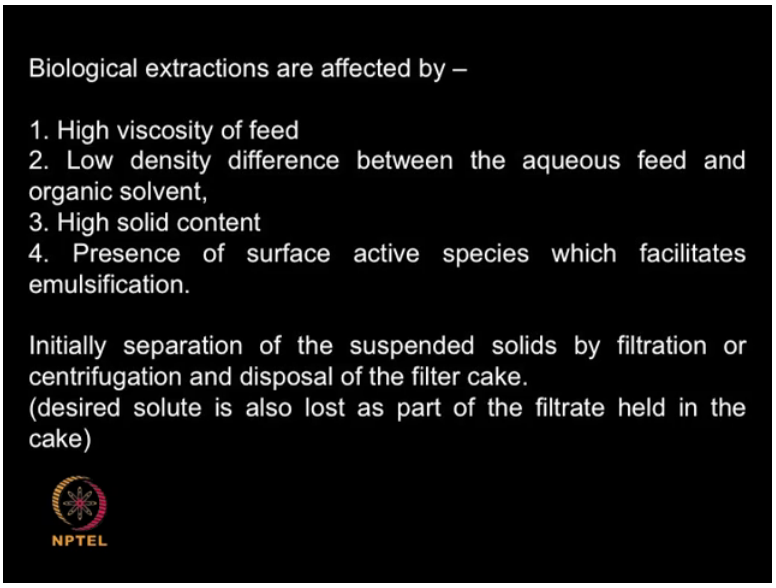

Now, if we look at biological systems biological systems create many problems during extraction. Unlike a normal chemical system because the feed will have a very high viscosity because of presence of cells bio mass intracellular material DNA cell debris and so on. So, the viscosity is going to be very high, so obviously your extraction efficiency is low there may be very low density difference between the aqueous feed and the organic solvent. So, if the density difference is very low then the separation time of the two streams into two different distinct layers is going to be a time consuming.

It will take a long time because most of the separation we assume is based on the difference in the densities, so the two liquids separate out nicely and we can remove the bottoms and the top layers independently of each other high solid content. As you know fermentation broth contains a large number of salts which you add, so there is going to be lot of solid present this solids are going to hinder your extraction. Now, there could be many surface active species present which may lead to emulsification of your extraction.

So, at the end of the extraction instead of getting two clear distinct layers you may end up with the multiple layers, you may have a foamy layer in the middle, you may have a solid layer in the middle. So, you may have instead of two layers you may have four layers, one could be your solvent and one could be your original broth. Then, there could be some layer which may contain a large amount of precipitated solid, there could be

another layer which may be having a froth or foams created because of the presence of the surface active species.

So, one way of overcoming this problem is to first do a filtration, so when we do a filtration the precipitated solids are biomass or surface active species can be removed. Then, you resort to the extraction, but then there is a problem you are the desired solute can also get carried away during the filtration process. So, you need to keep that point in mind some of your efficiency may go down during the filtration operation, so you have advantages, but again you have disadvantages. So, if the density difference is very low instead of resorting to the normal extractors which I talked about a in the previous class column extractors or a agitated extractors.

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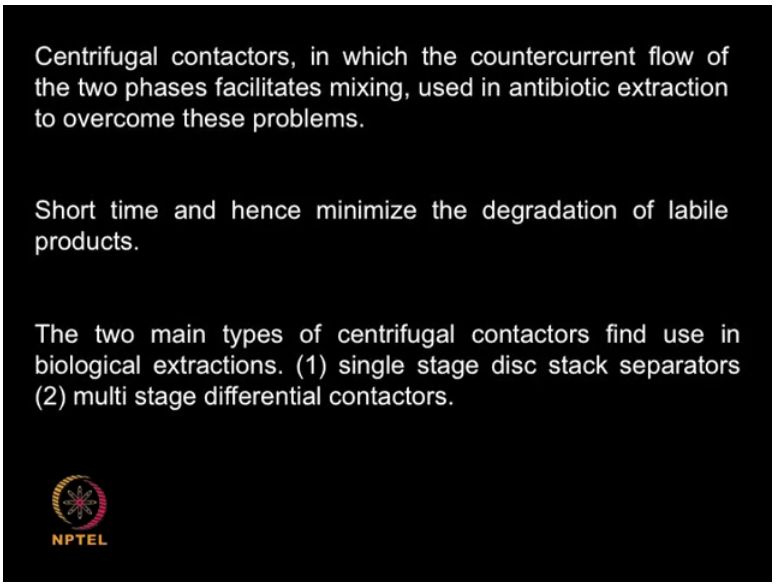

We may even go to centrifugal contactors now a days, a there is lot of interest in liquid liquid centrifuges where normal centrifuge we are use to is solid liquid centrifuge where you are trying to remove the solid or filter the solid out using a centrifuge. Here, we are talking about liquid liquid centrifuge and the density difference creates the separation, which means the higher density liquid will reach the walls faster because of the centrifugal force. So, the walls will have predominantly higher density liquid and the lower density liquid will be more in the middle portion.

So, centrifugal contactors are another way of separating out these two layers instead of resorting to a settling based on a simple gravity. So, the advantage it is going to be

shorter time because separation can be achieved because of the high forces you are using. It is practiced in an extraction of antibiotics from the fermentation broth there are two types of centrifuges.

You can resort to for biological systems one is the single stage discs stack separators other one is the multistage differential contactors. So, just like the solid liquid centrifuge where we have stack of discs placed in the middle or near the shaft you can also here also have a stack of discs, but it will be a single stage. Then, another approach by which you can achieve is having multiple stages of centrifuge, which means you will have more than one set of centrifuges for separating out the two distinct layers of the liquid.

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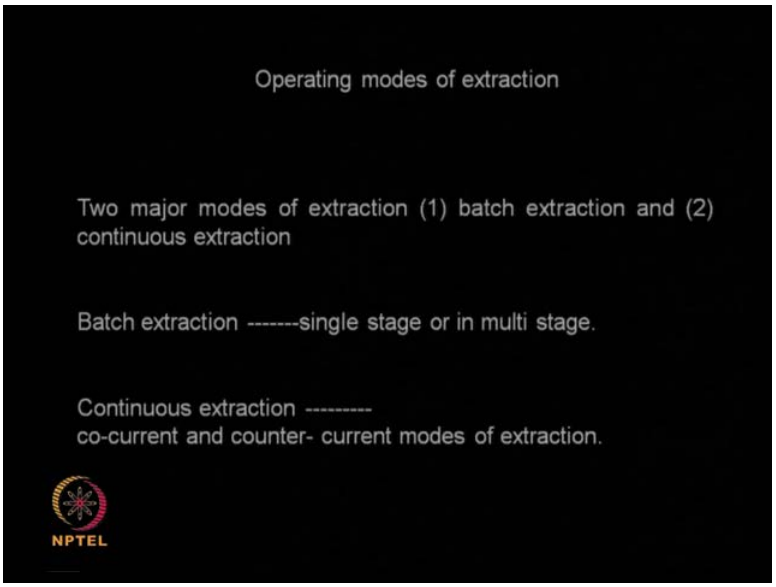

Now, you can perform this liquid liquid extraction either in a batch mode or in a continuous mode. So, in a batch mode you can have a single stage that means you have one big vessel where you mix both the liquids and you have separations taking place or you can have many small vessels. Each vessel can be considered as a stage where there is a contact between the two fluids and the separation or the extraction takes place in each stage.

So, that is called a multistage batch operation the continuous extraction can be done either in a concurrent mode or in a counter current mode. That means, both the streams may be flowing in the same direction that means that is called co current or the streams could be flowing in opposite directions, which is called the counter current. Counter

current is generally preferred, because the extraction efficiency is much higher than the concurrent mode.

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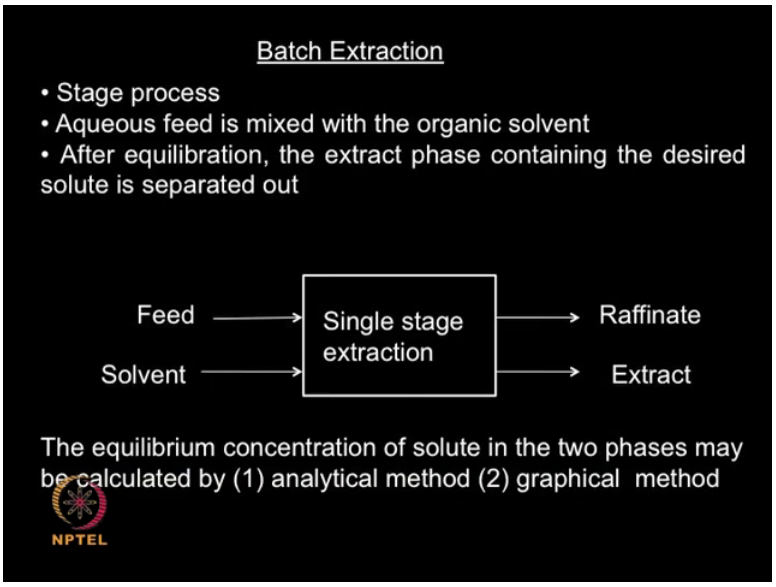

Actually, let us look at the batch extractor it is a stage process the aqueous feed is mixed with the organic solvent. Then, once they have reached an equilibration there two layers get separated your desired solute is present in the extract the raffinate is the as feed. Both these streams are taken out, so we can calculate what the equilibrium concentration of the solute in these two phases is. We know the concentration that is entering the feed and after the extraction we will be able to calculate the concentration in this as well as in this place. There are two ways by which we can do one is called the analytical method other is called the graphical method.

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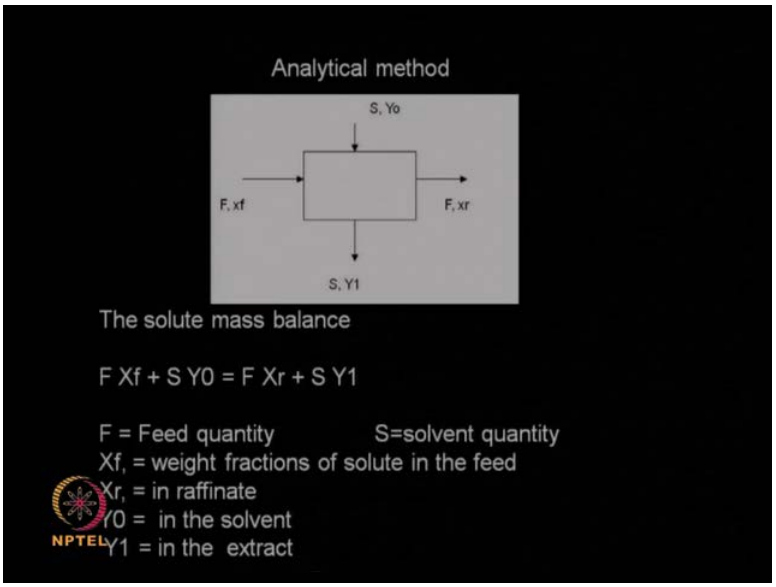

let us look at analytical method let us just draw a stage you have a feed entering and the concentration of the solute in the feed is X f the feed is leaving after the extraction the same amount of feed concentration of the solute is X r in the raffinate. Now, you are introducing a solvent and the concentration of solute in the solvent is Y naught and it has picked up or it has extracted your solute. So, the concentration has gone up from Y naught to Y 1 the most important assumption here is the miscibility between the feed and the solvent is 0. If there is going to be miscibility, then a F will not be same here as well as here S will not be same here as well as here.

So, keep you have to keep that in mind one of our main assumption is there is no miscibility between the two streams that is why when you select a solvent, you have to be very careful. So, that you they are not miscible with each other if you are going to have a miscible system, then the efficiency will fall down dramatically, now we have two streams that are entering and two streams that are leaving.

So, we can make a mass balance for this quite straight forward we have been doing mass balance for the past several classes. So, we can do a mass balance for the solute F into Xf that is F is the flow rate X f is your concentration that is the amount of solute entering in this stream S into Y naught that is the amount of solute entering from the solvent stream. This is the amount of solute entering in the feed stream, this is the amount of solute entering in the solvent stream. Now, there are two streams that are leaving your stage one

is the solvent other is the raffinate, so again you can do a mass balance on this side F X r plus S Y 1. So, this is your entire overall mass balance for the solute inputs is equal to output quite straight forward.

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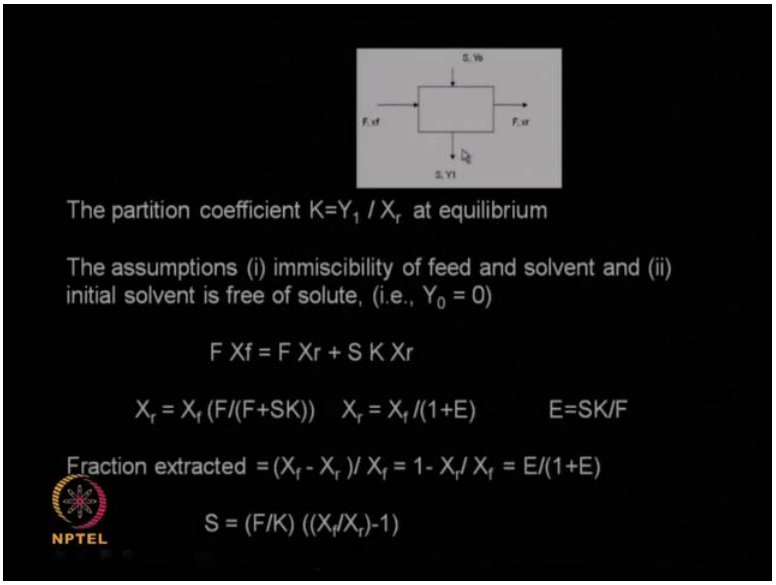

So, once you do that and we know that the partition coefficient K is given like the ratio of the concentration of your two solute concentrations in these two streams. So, it will be K is equal to Y 1 by X r and Y 1 is going to be larger than X r, so obviously K will be larger than 1. So, higher the value of K more efficient is your extraction process, so the assumptions immiscibility of the feed and the solvent number 1 number 1 when initial solvent does not contain any solute they Y naught will be equal to 0.

So, we put Y naught equal to 0, so what happens F into X f the Y naught term has become zero is equal to F into X r plus S into K into X r. Instead of Y 1, I put K into X r here, now we can rearrange to get X r X r is the concentration leaving the stage is equal to X f multiplied by F divided by F plus S K. Now, we will call E efficiency factor E is equal to S K by F, so if you do that then what you get X r is equal to X f by 1 plus E that means X r is equal to X f that is the concentration entering divided by 1 plus E and E is going to be larger than 1.

So, 1 plus E will be larger than 1, so X r will always be less than X f because you have done some extraction. So, the concentration here will be much less than the concentration in the feed, now what is the fraction extracted fraction extracted is given

by X f is the initial concentration, X r is the concentration after extraction divided by X f. So, X f minus X r by X f, so if you rearrange and substitute this you will get fraction extracted equal to E by 1 plus E.

So, this is a very important equation because when I have extraction liquid liquid extraction, I would like to know given the particular value of K. Given a particular value of the solvent, flow rate given a particular value of feed flow rate or heavy flow rate how much fraction that can be extracted in the stage. So, all you need to do is calculate E from this E is equal to SK by F, then E divided by 1 plus E gives you the fraction extractor. So, similarly, by doing a mass balance we can get equation for Y 1 as well that is the amount in the in the solvent layer.

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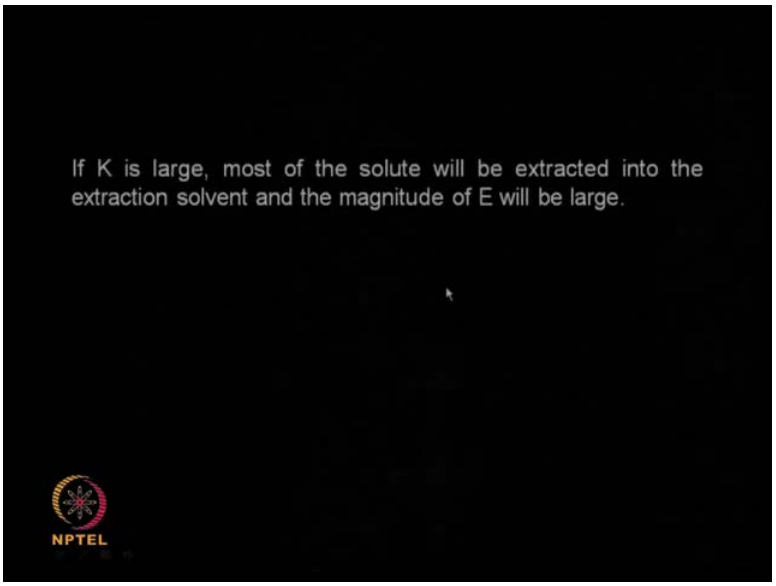

So, if K is large most of the solute will be extracted into the solvent because E also will be large. So, if K is very large if you see this equation E is equal to SK by F, so if K is very large E also is going to be very large, so you select a solvent so that your K is very large.

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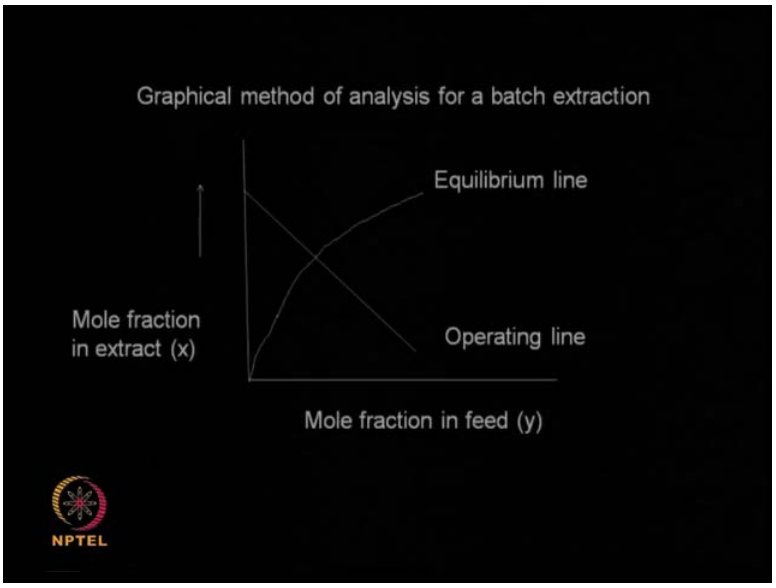

How do you use a graphical method for solving just like a adsorption, if you recall you will have a operating line you will have a equilibrium line. The operating line is your mass balance the equilibrium line is nothing but your y is equal to k x type of line. So, why does there is a slight bend here, the bend could be because you may have different the k changing as a function of a concentration. So, in that case, then you may have a bend otherwise if k remains constant irrespective of concentration. Then, this also should be a straight line, so just like in adsorption we will see where the equilibrium line intercepts with the operating line. That particular point will be the concentration of the solute in the solvent layer that is leaving the liquid liquid extractor.

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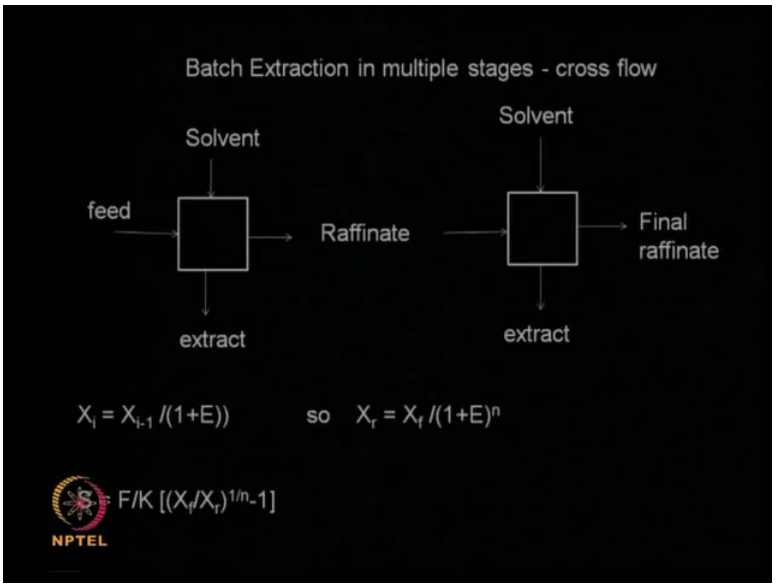

Now, let us go to a multi stage system all we did so far is single stage system that means you have one unit or a one stage where you mix your solvent with this with the feed, and then you separate them out. So, extraction is done in one stage generally extractions are not very efficient in a single stage you need multiple stages 3, 4, 5, 6 and so on actually. So, let us see how the equations differ when you have multiple stages the first type of a stage operation, let us consider cross flow design that means you have a stage your feed is entering solvent is entering here its extracted.

Now, whatever has been extracted raffinate that goes to the next stage, again you are adding some fresh solvent something is getting extracted. So, again the raffinete leaves from stage 2 that goes to stage 3, again fresh solvent is introduced. Again, you extract like that you can have large number of stages, you can call it n stages and you are every time adding fresh solvent, so all these extracts from each of the stage will be combined together.

Then, that particular extract will be very rich in your solute this is called a cross flow because your feed is flowing like this your solvent is coming cross wise from the top. Every time the assumption here is you are adding fresh solvent that means concentration of the solute in the first solvent is 0. So, you can have a general equation like this Xi that is concentration of the solute leaving the stage i will be equal to concentration of the solute entering the stage divided by 1 plus E. If you do a overall mass balance

considering n distinct stages X r that is a concentration of the solute in the raffinate will be equal to X f divided by 1 plus E raise to the power n, n is your number of stages very simple equation very simple equation.

So, if I give you n stages and if I give you the value of the K the amount of a solvent you are taking the amount of feed. You can calculate what will be the final concentration of the solute in the raffinate after n stages or conversely we can do it the other way. If I want to have an extraction efficiency of say 90 percent how many stages, do I require, so I can do that sort of calculation. So, we can do both types of calculation understand given value of K given the value of S and F and given the number of stages I will know everything on the right hand side.

Then, I can calculate what will be the concentration of the solute in the exit or given that I want to recover 90 percent of my feed that means a X r will be point one X f and if I know, I can calculate n. So, I can do both, so this equation becomes very important if I am using a multistage stage cross flow extraction system, how many stages do I require or what will be my extraction efficiency.

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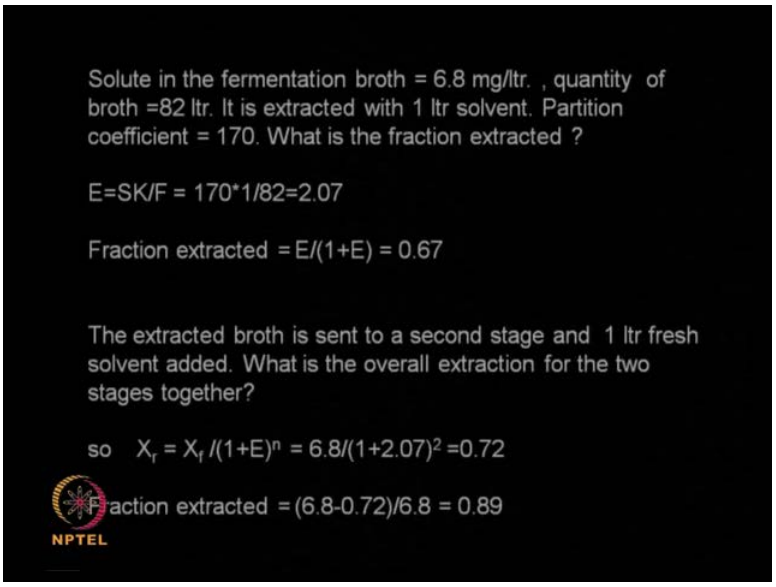

Let us look at one or two problems, so that some of these concepts get really clear up there is some solute in a fermentation broth the amount is 6.8 milligrams per liter quantity of broth is 82 liters. Now, I add 1 liter of solvent to extract this solute the partition coefficient is 170, you see you will you select a solvent. So, the partition

coefficient is very large, so the partition coefficient is 170, what is the fraction extracted very simple. First you have to calculate E, E is given by SK by F S K by F, so your K is 170, S is 82 liters, sorry S is a 1 liter and your F is 82 liters.

So, you get E as 2.07 fraction extracted formula is E divided by 1 plus E, so if I substitute these terms here, I will get 0.67 that means 67 percent of the fraction of the feed can be extracted in a single stage. Now, imagine I am using another stage and I am adding again 1 liter of this solvent to whatever has been extracted. I want to calculate what the overall extraction efficiency what is the overall extraction efficiency is.

Now, I have two stages this is also a cross flow understand, because I am again adding fresh solvent one liter fresh solvent in the second stage. So, the feed with the raffinate which is leaving stage one goes into stage 2, now you want to calculate what the overall extraction efficiency is. So, n here is 2 you know your E, so again you substitute here, so you get a fraction extracted as 89 percent. So, if I have one single stage I will extract 67 percent of my solute, if I have two stages the overall efficiency is 89 percent.

So, if I have three stages it may go up to 92 percent, if I have four stages it may go up to 95 like that you know because you have 1 plus E raise to the power n, it will not be a simple algebraic addition type, but it will be in this slow steps. So, one stage will have very high extraction second stage overall will come down and so on, actually if you are really interested in extracting all you are a solute it could be a protein of interest. It could be an antibiotic of interest, so you may resort to several stage operations, so that you recover as much as possible completely as possible.

So, this is a cross flow type of design, so we will later on look at counter current flow type of design. The main disadvantage of cross flow is every time you have to add a fresh solvent that means the solvent usage is going to be very high, whereas in the counter current design the solvent which is leaving stage 1 will enter stage 2. That way you are not using too much of solvent unlike the cross flow design. The equations for the counter current design changes when compared to your cross flow design we will look at it later, but before that we will look at something else now.

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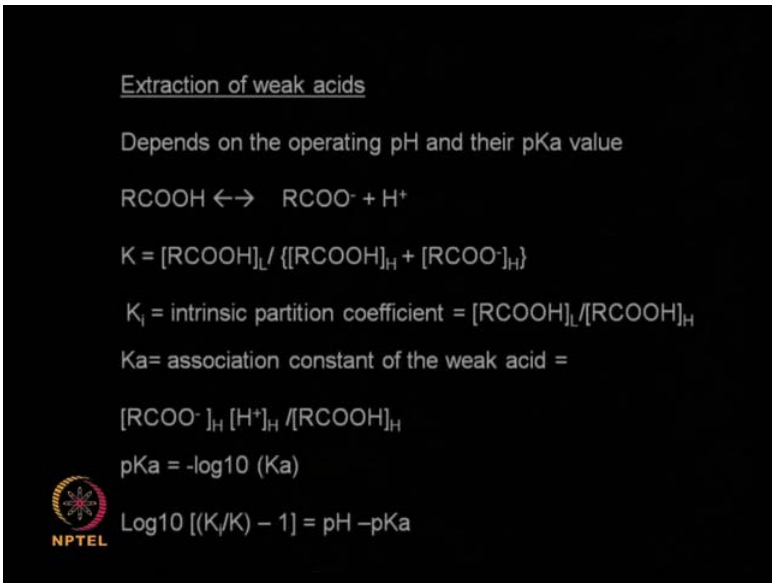

So far we assumed that the solute does not dissociate, but then in many situations at different pH conditions the solute may dissociate it could be a weak acid or a weak base. So, when something dissociates the number of species present also increases and dissociation normally takes place in aqueous medium because only in water a salt can dissociate in acid can dissociate into proton. A base can dissociate into a hydroxyl ion, but not in the solvent medium, please remember that actually and this dissociation depends upon the pH condition.

So, depending upon the pH and whether it is a weak acid or a weak base it will dissociate faster or it will not dissociate faster. Let us look at dissociation of weak acids and how your equations are going to get affected because of that imagine a weak acid RCOOH it dissociates to RCOO minus and H plus. Now, the equilibrium partition coefficient K by definition there are two species here and there is one specie here actually.

So, you have to keep that in mind and the overall K is given by RCOOH in the light phase light phase is the solvent phase and RCOOH in the heavy phase. The point in heavy or aqueous phase is the acid is present in this form as well as in the RCOO minus form. So, you need to consider both the species do not forget that, whereas in the solvent phase it does not dissociate like if it is a solvent like chloroform or methanol it does not dissociate. So, there is only one species so here we have only one species in the light

phase or the solvent phase, whereas here we have two species in the heavy phase or the aqueous phase and the two species are RCOOH and the RCO minus.

Now, let us look at K i that is the intrinsic partition coefficient can be RCOOH in the light phase RCOOH in the heavy phase. So, these two partition coefficients are different this is K which considers all the species whereas, this is K i which considers only the r acid. Now, K a is called the association constant or the weak acid and that is given by RCOO minus into H plus divided by RCOOH.

You might have studied long time back this is called the association constant or the dissociation constant and the pKa is the negative logarithm of Ka to the base 10. You must have all heard about pKa now this pKa, K i, K are all inter related in this form logarithm to the base 10 Ka minus K minus 1 is equal to pH minus pKa. So, pH has a very strong effect on these terms because pH affects the dissociation of the weak acid to proton, so that way pH will have an effect on these dissociation constant as well as with respect to the your partition coefficient.

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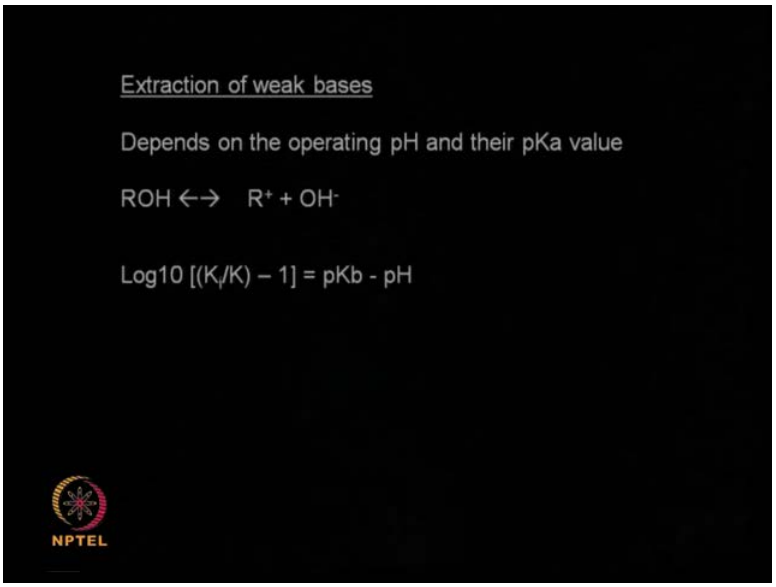

Similarly, for weak bases also as you know weak bases ends up with the hydroxyl ion and you are going to have instead of pKa here you are going to have pKb, so this is how the equation looks like where the pH has an effect on the partition coefficient.

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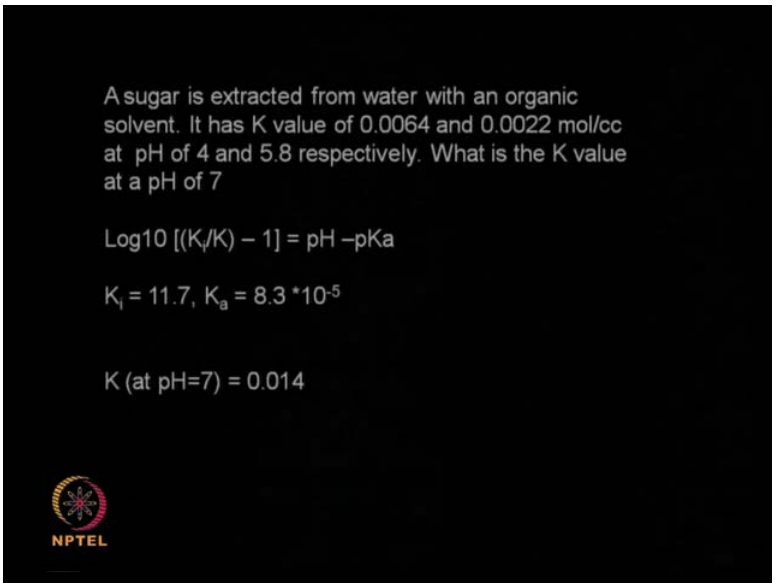

Now, why is it so important that comes out from a problem imagine, I want to extract a sugar from water with an organic solvent so it has got a K value of 0.006 4 moles per cc at pH of 4 it has got a K value of 0.0022 Moles per cc at a pH value of 5.8. You see the K values changed K value have changed because of the pH effect because the disassociation of the weak acid. Now, I would like to calculate the K value at a pH of 7, so if a the K value changes that means if your partition coefficient changes the efficiency of extraction also is going to change. So, you need to identify the best pH where your K is maximum so that your extraction is also very high.

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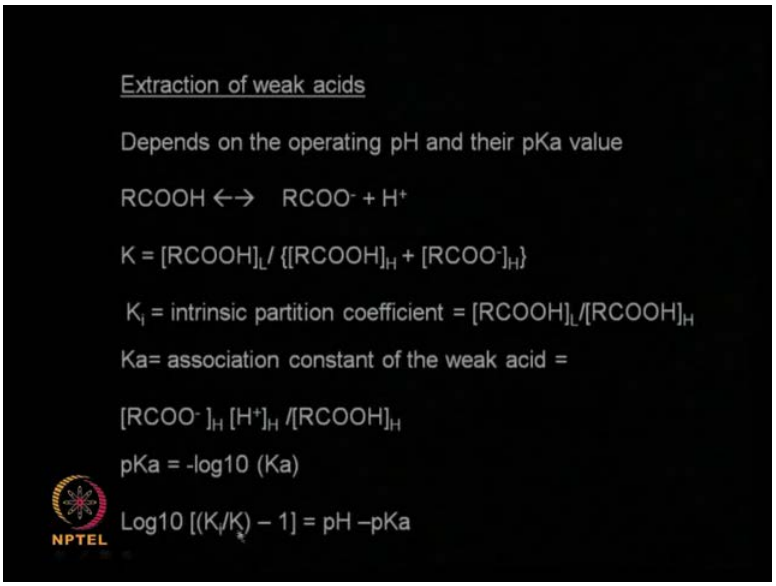

So, all you need to do is you need to substitute into this previous equation locked and K i by K minus 1 is equal to pH minus pKa, I know at two different pH what is my K value, so I can calculate K i and pKa from those two equations. So, once I calculate i at pH of 7, I can calculate what will be my K value very straight forward, so I have been given at two different pH the K values.

So, from those two equations I can calculate the Ki and pKa for the system, once I calculate for a pH of 7, I can calculate what will be K. So, one important you need to keep in mind that a the K varies depending upon pH for weak acids and weak bases. So, you need to identify the best pH so that your K is maximum if the K is maximum you are going to have a good extraction. So, you may have to do lot of experiments effect of pH on the extraction efficiency before you decide on the pH.

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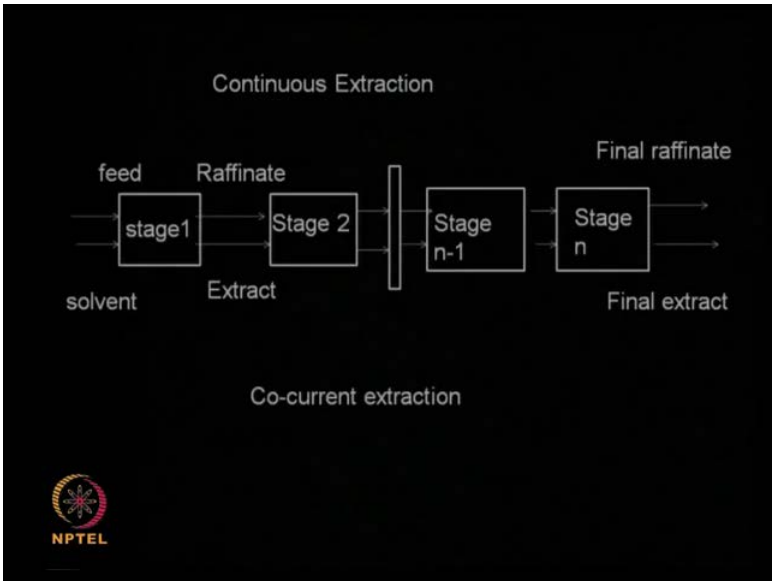

Now, we looked at cross flow design and I said it is not very efficient because every time in each stage you need to add fresh solvent, so the solvent usage is going to be very high. So, there is something called a concurrent design and a counter current design, so in a concurrent design what you have is you have the solvent entering stage one feed is also entering stage 1.

Then, both of them are leaving stage one and then both of them enter stage 2, they get mixed and then there are two streams leaving and so on. So, it keeps happening for end stages, so you have finally, a raffinate starting from a feed and then you have a final

extract, so the same solvent is flowing in all the stages extracting the solute at each stage. So, you are not adding any more extra solvent, so the solvent usage is not very high, so that is a main advantage of these types of designs.

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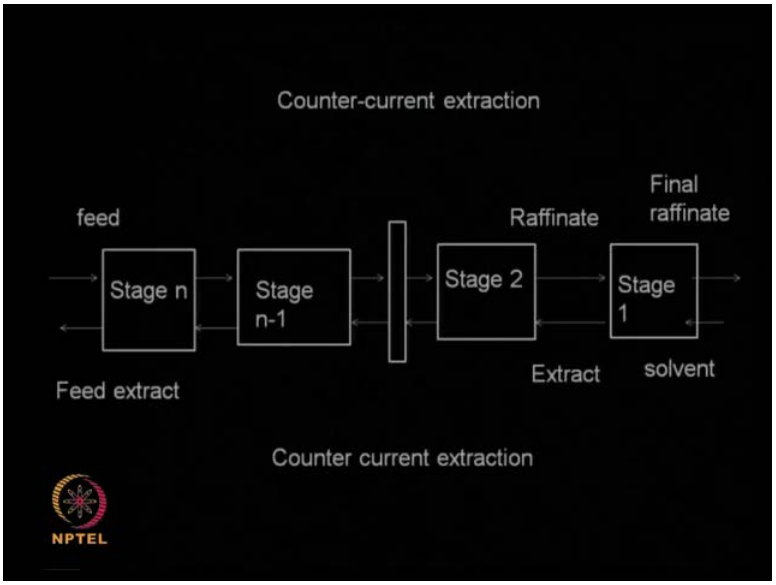

Contrary to co current, this is a counter current system, so what is happening here the feed is entering here moving all the way going down up to stage n your feed is entering here from the left going all the way. So, both these are moving counter current to each other they both are moving counter current to each other and you are going to have n stages in this particular design. That is why it is called an end stage counter current design so again the advantage is you are not adding any fresh solvent in this particular case.

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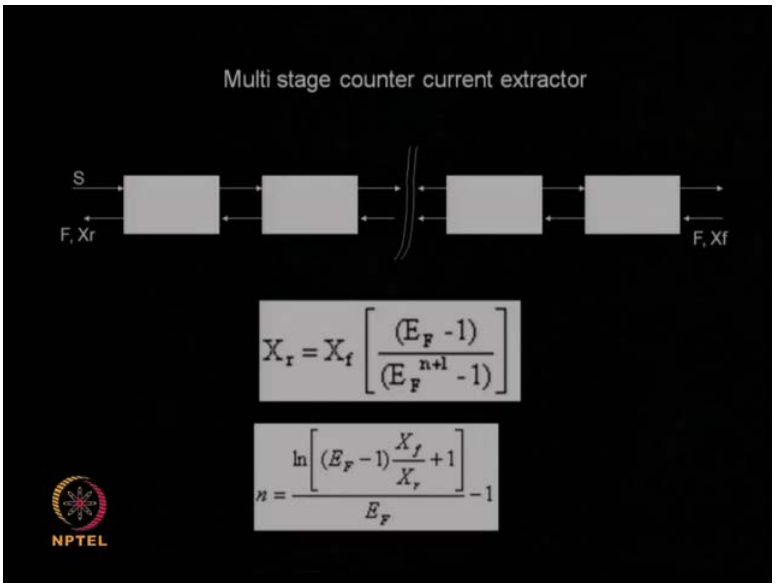

Let us try to derive some equations for a counter current multi stage process imagine you have n stages your feed is entering from this end at a concentration of the solute as X f and after n stages of extraction the raffinate contains concentration of X r. Your solvent is entering from the left hand side and it is travelling in each stage and then finally leaving the train. So, the solvent that is entering on the left hand side is a fresh solvent, so it does not contain any solute, but after the stage 1 it would have picked up some solute.

So, whatever solvent entering stage two or subsequent stages will always contain some solute and a the streams that are leaving, for example if you take these stage these are the two streams if you take this particular stage these are the two streams. If you take this particular stage these are the two streams, if you take these stage these are the two streams and these two streams are on equilibrium. The solute concentration in these two streams are an equilibrium and K is the concentration of the solute.

The solvent that is leaving this particular stage divided by the concentration of the solute in the raffinate in this particular stage. So, if you take this stage for example, the solvent that is leaving is here so there is a difference between the solvent that is leaving and the concentration of the solute in the feed stage. So, if we do that, you can do a mass balance for each of these stages and when you do a mass balance. You can connect the concentration of the solute that is entering from the feed to the concentration of the

solute that is leaving the train of counter current stages with the concentration of the solute that is leaving with the solvent. Of course you assume that the solvent that is entering your extractor train does not contain any solute.

So, if you do that you will end up with the this type of equation where X r is the concentration of the solute that is leaving the n stages and X f is your feed concentration E f is your extraction efficiency n is the number of stages. So, E f is nothing but SK divided by F S is the amount of solvent you take and F is the amount of broth or the aqueous or the heavies you take. So, the equation looks like this where X r is the concentration of the solute in the raffinate X f is the concentration of the solute in the feed. So, there will be a massive decrease in the concentration from X f to X r because of this particular term E f minus 1 divided by E f and plus 1 minus 1.

So, what can we do with this equation we can use this equation to see what will be the amount extracted starting from a feed concentration of X f going down to X f, X r. If I know the number of stages n or conversely I can calculate the number of stages if I know what efficiency of extraction I desired. So, if I say ill want to reduce the concentration in the fermentation broth from 10 millimols per liter to 1 millimol per liter using a solvent of so many liters. If I know the k value how many stages do I require in a counter current extraction system, so I can use this equation and i can calculate what will be my n that is number of stages.

So, I can use this set up equations for two different purposes, one is to calculate the extraction efficiency when I know the number of stages. When I know the operating conditions the other is to calculate the number of stages required to achieve a particular extraction efficiency. So, that is the beauty of this particular set up equations, so I can use it for simulation purposes as well as I can use it for design purposes. So, we looked at two different types of train of extraction stage process 1 is the cross flow system and the other one is the counter current system,

So, for both these systems the equations for extraction efficiency is quite different from one another. It depends upon the operating conditions like the quantity of feed you take the quantity of solvent you take the partition coefficient the k value. So, these determine either extraction efficiency or the separation efficiency.

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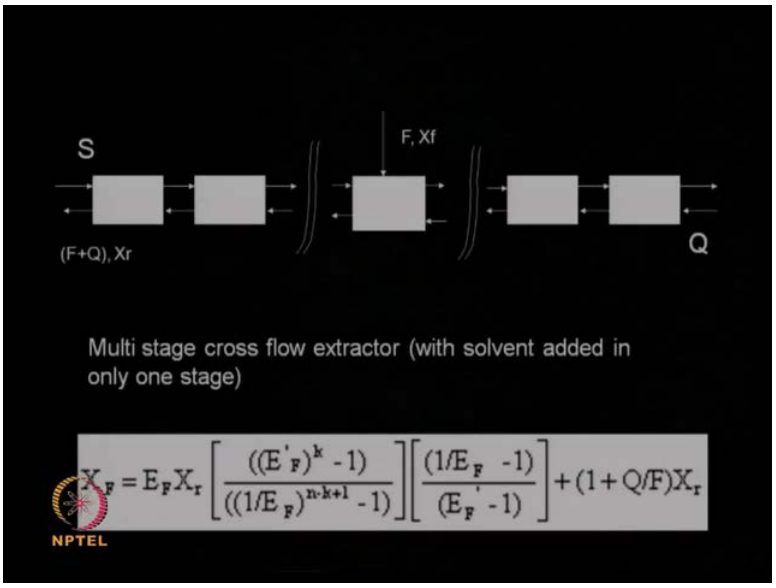

Now, there is one more type of design which is slightly more different, you are introducing a feed somewhere in the middle rather than from one end you are introducing it from the middle like this. So, introducing your feed at a concentration like this and from one end you are introducing just the heavy liquid without any solute that is quantity of Q. So, F plus Q gets added up here and the extraction concentration changes or decreases from X f to X r. Now, your solvent is introduced from the left hand side and the solvent is a free from any solute that means, there is no solute present in the solvent and it moves here.

So, again solvent is added only if in one place like a normal counter current system actually. So, this design is slightly more complicated when compared to the previous simple counter current type of design because your feed is added somewhere in the middle. So, when you take this type of system and you perform mass balance you end up with an equation slightly more complicated looking actually, so this equation again you can calculate the concentration of the solute in the final raffinate.

So, if you look this side you will have Q as your heavy and S as your solvent flow, whereas if you look here this side you will have F plus Q coming in and F plus Q going out and S is you solvent flow. So, you can consider this as one set of counter current system and this as another set of counter current system and you can perform a mass balance to get an overall mass balance for the entire cross flow multi stage extraction

system. So, again this equation can be used for many purposes we can calculate how many stages I require if I want to extract a solute from a concentration of X f to X r or if I know the X f and X r, I can calculate, how many stages, do I require in addition.

We can also calculate what should be the place where I introduced my feed should I should be introduced in stage 1 stage 2 or stage 3 because that is K, K tells you the K introduction of the feed in the k stage. So, I can use this equation to calculate where should I introduce my feed to get a best separation, so should I be introducing the second stage or third stage or forth stage and so on. Actually, here this type of design has one more parameter which you can play around with for improving your separation efficiency, whereas in a counter current system you had only the end there. That is number of stages, whereas here you have n as well as k n is the number of stages k is the stage at which you introduce your feed.

So, we can play around with both n and k to get the best separation efficiencies, so again all though this equation looks very difficult or complicated it is again all based on mass balance. There is no reaction taking place in extraction you just have mass balances happening you have a mass balance for input mass output. Then, you just equate the input equal to output and that gives you a balance for one stage and so on, so you build up the multistage process.

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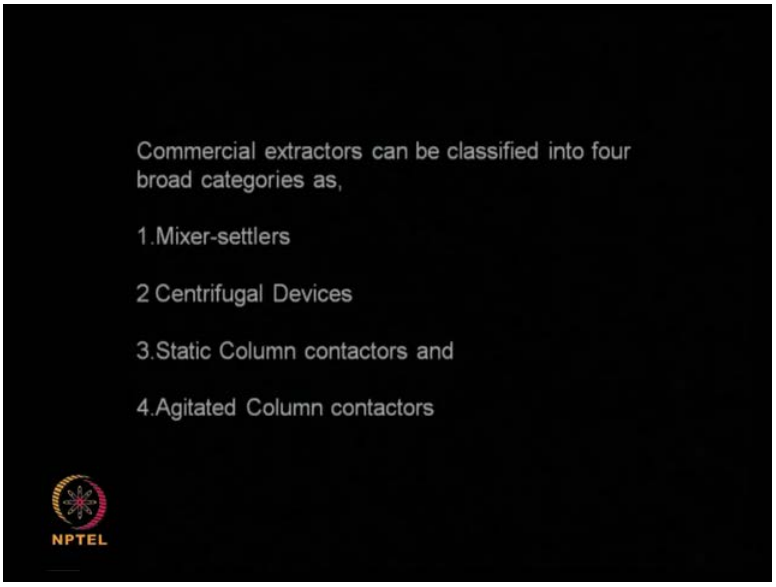

Then, commercially there are many types of extractions that are used one is the mixer settler mixer settler is nothing but you mix your solvent with the feed using a mechanical agitation. Then, allow them to settle down or allow the layers to separate out under gravity condition that is called mixer settler. Next is a centrifugal type of a design where I as I explained when the density difference between the two streams are minimal, then you can use centrifugal forces to achieve the separation of the two streams.

If the density difference is large we can use a normal gravity type of settling the centrifugal liqiid liquid centrifugal separators are popular. If the density differences are minimum third is the static column contactors that means you have large tall columns where the two streams come in contact, but there is no mechanical agitation. So, you have you have like a jet contactor or you can have a bubble column contactor and so on. Actually, in agitated column you have a column you also have a mechanical agitation which creates turbulence and mixing of both these streams.

So, again the idea is to improve your mass transfer so these are the four types of designs which we employ in a industrial scale to achieve a good liquid liquid extraction each of them have advantages and disadvantages. If you go for a mixer settler, the floor space will be very high if you go for a column design, it occupies minimum floor space. If you go for agitated design mass transfers are very high, but the disadvantages you need mechanical motors to operate.

So, your operating cost is very high centrifugal devices are a very efficient it consumes a very little time for extraction, but then your cost may be very high your operating cost also may be high. So, each one of them have their advantages and disadvantages and one selects based on their requirements and the criteria of the separation. So, these are the two factors which one need to considered and as I mentioned in my very beginning of this there are two important principles which one need to consider. One is the thermodynamics, thermodynamics determines the partition coefficient and kinetics determines the rate at which the solute moves from the heavy phase or the aqueous phase into the solvent phase of the light phase.

So, if the partition coefficient is very high that means concentration of the solute in the solvent layer will be much higher when compared to the concentration of the solute in the raffinate layer. So, your efficiency of separation is very good if your mass transfer is

very high the rate at which the solute moves from the heavy phase into the light phase is going to be very high. That means I can a do the extraction job very fast ideally would like to speed up the process of extraction so that the overall time of extraction is minimal. So, how do you achieve higher mass transfer by improvising surface area by creating turbulence by having a lower viscosity and so on.

Actually, how do you achieve a better extraction efficiency or partition coefficient we cannot do much about it we have to have a solvent selection. That means in my lab I go and select a suitable solvent which will have a very high partition coefficient. Operationally, I will not be able to modify k, but I need to actually select a proper solvent which will have a higher value of k or the partition coefficient, that is the only thing I can do. Then, as I explained partition coefficient alone might not be enough because there might be several other factors you need to consider when you are selecting your solvent because of the safety issues involved because of the cost because of the recoverability.

The selectivity means the solvent should be selectively extracting only the particular solute of your interest instead of a extracting other solutes. So, all these factors also come into picture and you need to consider those aspects also when you select your solvent, but the mass transfer affects the rate at which the solute moves into the solvent phase. The thermodynamics determines the partition coefficient or the ratio of the concentration of the solute in the light as well as in the heaviest layer actually. So, one can play around with operating conditions one can play around with the solvent selection criteria to have a best extraction process.