Downstream Processing
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Lecture - 16
Liquid –Liquid Extraction

Today, we are going to start a new topic that is called a liquid liquid extraction. This is a thermodynamic process where there is an equilibrium of the solute in 2 different phases. So, liquid liquid extraction has many advantages and it is widely used in bioprocess downstream technology. It is a mass transfer operation.

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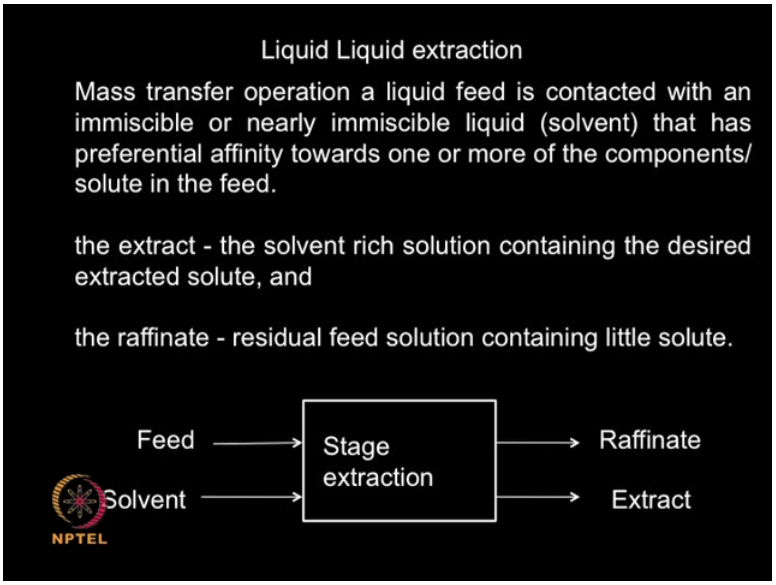

So, you have a liquid feed; it could be a fermentation broth or a reaction broth which contains the solute or metabolite or the protein which you would like to recover. We use a solvent; the solvent is a immiscible solvent or very sparingly miscible and this solvent will extract preferentially the solute of your interest. You cannot say it that only one solute will get extracted because after the end of the fermentation broth you may have a large number of metabolites. So, you may have some of the unwanted metabolites also getting extracted; but that is possible.

So, typically in a liquid liquid extraction you have a stage where you make your feed come in contact with the solvent. The solvent could be a low density liquid or it could be a high density liquid. So, once the contacting is done and you allow the two layers to

separate out; that means, if you want the two layers to separate out, there has to be some difference in the density. The density difference is very very small then the separation is not very efficient and it may take a very long time to separate out. So, in that situation you may resort to a centrifugation type of a operation.

So, the two layers get separated out and the solvent layer may be in the bottom; if it is very heavy or may be in the top if it is light. And, this solvent carries the solute of your interest; so here you have the extract which will have the solute rich solvent layer. And, you have the raffinate which would be now either devoid of the solute or will have less amount of solute when compared to the feed.

Now, these two streams that is the extract and the raffinate will be in equilibrium with each other. The solute partitions between these 2 phases; so, the key word here is partition. So, there is something called a partition coefficient which determines how much of solute from the feed goes into the solvent layer. If the partition coefficient is very large, then your solute will be predominantly found in the solvent layer. So, you select your solvent which will have a very high partition coefficient; so that, you will have more of the solute into the solvent layer. Sometimes, you may have to do it in many stages; instead of just one single stage, you may have to do it in 2, 3 multiple stages.

So, here in a batch process if you consider, you mix your solvent with the feed thoroughly agitated with the stirrer and then stop the stirring; so that the two layers get separated out. And, then you take the solvent layer which contains more of your solute and you can now take the original feed and perform another extraction process. This is how we do it in our lab. So, liquid liquid extraction is very very simple; all you need is a separating funnel and you can do it in your lab very efficiently. It does not require high temperature or pressure; it is done in ambient conditions.

So, it is very ideal for solutes which are very temperature sensitive; it is very ideal for proteins because proteins will never get denatured. So, it is very widely used technique except that the solvent should not denature your protein of interest. Sometimes, the solvent may take away the water present in the enzymes, there by denaturing your enzyme or protein; so, that is the only point you need to keep in mind.

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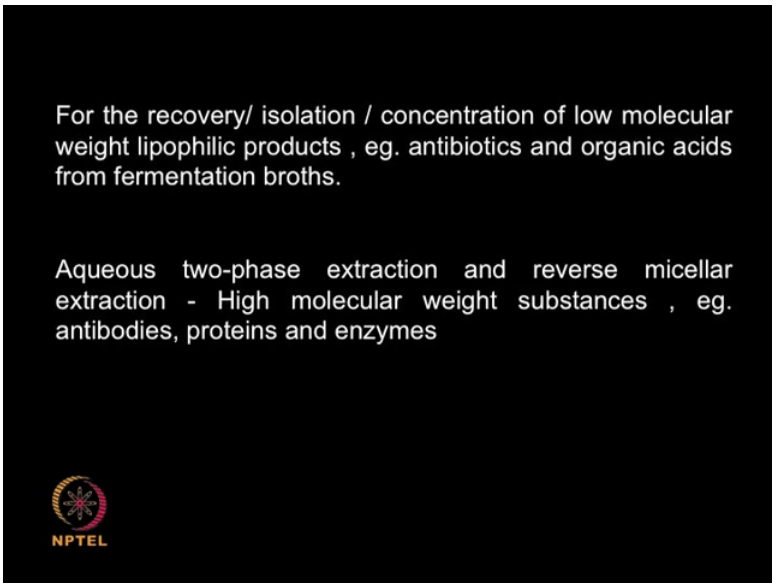

So, it is ideally used for low molecular weight, lipophilic products; like antibiotics organic acids from fermentation broth or if I can use a aqueous two phase extraction system for high even high molecular weight substance, antibodies, proteins, enzymes. So, this technique is widely used for a large number of separation and purification downstream processes. It is a thermodynamic process as I said because there is an equilibrium between the streams that are leaving the stage.

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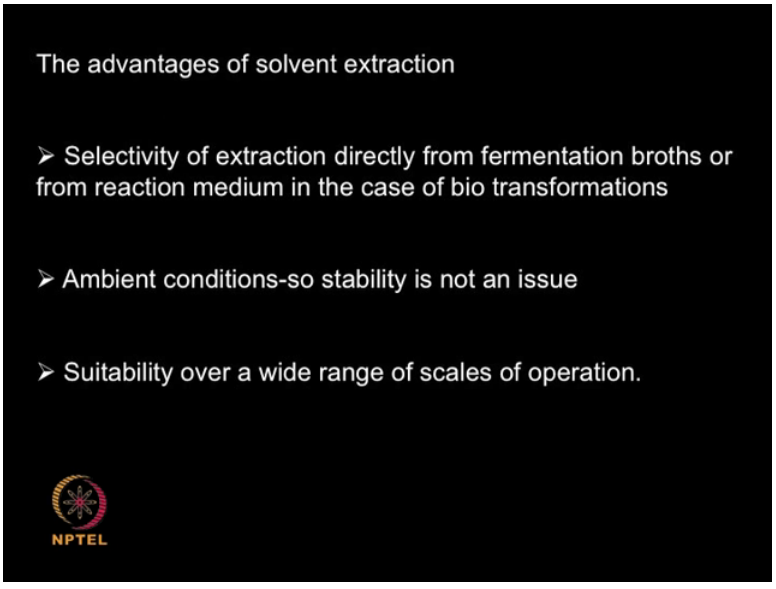

Advantages of liquid liquid extraction; you can very selectively extract a particular metabolite or protein. So, by selecting your solvent or aqueous phase, selectivity can be tremendously improved. It is done in ambient condition; so, stability or a un stability problems, in stability problems is not a issue. And, we can use it at wide range of scales. As I said, we can practise this in your lab or you can take it to thousands of litre scale in an industrial set up as well. So, as long as you are able to have a solvent which has a very high partition coefficient as long as you can recover the solvent and re use. Then, this is the best method for even for large scale operations. And, of course, we do it regularly in our lab as well actually.

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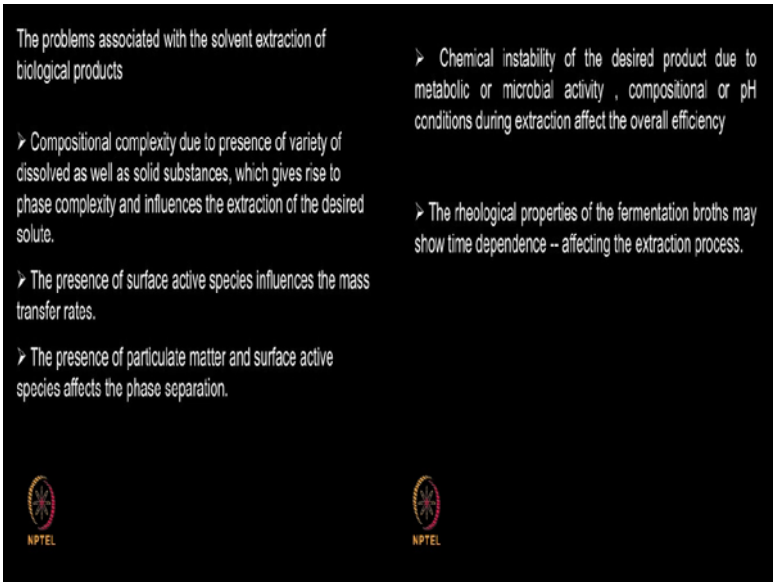

But there are problems also you need to consider; when you are resorting to liquid liquid extraction. There could be solids present in your fermentation broth, this can give rise to phase complexities and it can influence the extraction process. That means, the separation will not be a clean two phase separation. There could be a small layer where there could be some of the solids precipitated out may be present. So, there some of your product of interest may get lost. So, instead of just having 2 clear layers the solvent and the raffinate layer you may also have a solid layer in between.

If there are surface active species, then your mass transfer rates gets disturbed. That means, mass transfer of the solute from the fermentation broth or feed rich layer into the solvent layer. Number 3, if there are surface active species present; then, these will affect

your phase separations, there could be adsorption taking place which may reduce the efficiency of separation.

There could be chemical instabilities as well. So, the desired product when getting extracted may leave a loose, big it is activity; because of changes in pH, changes in compositional conditions and so on actually. Then, the rheological properties also are getting disturbed; if you take fermentation broth if it contains cell mass, dead cell debris and so on, it will be highly viscous. And, we need to now mix your solvent with such a highly viscous fermentation broth. So, the rheological properties will have a bearing on the extraction process; so, you need to keep those points also in your mind actually.

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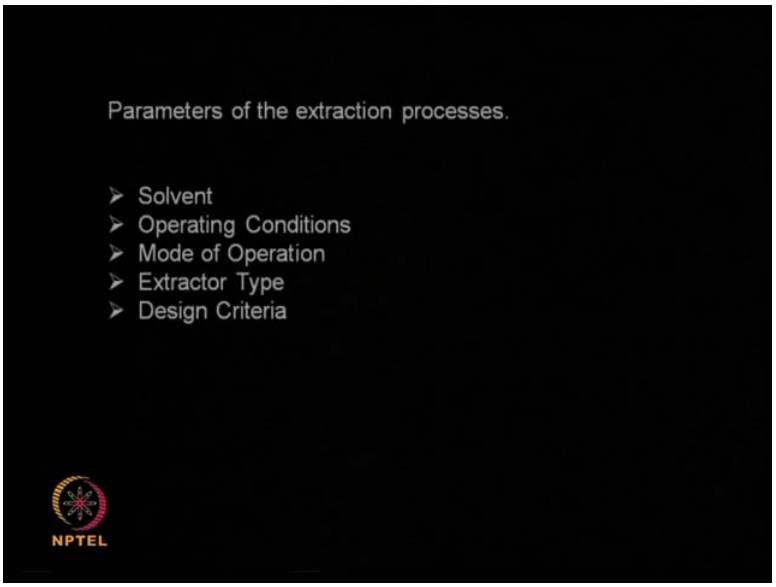

So, there are many parameters which affect your liquid liquid extraction process. The type of solvent you select, how efficient it is, what is the partition coefficient of your solute in the solvent. So, all these issues needs to be considered; so, when you select your solvent we need to consider all these points; we will talk about it in the subsequent slides on solvent selection. Operating conditions, what should be my temperature what should be my ph and so on these are the operating condition.

If I am using a continuous extraction what will be the flow rate of the solvent, what will be the flow rate of the feed. If I am using an agitator, what should be the agitation speed and then if I am going to allow the two layers to separate, how long should I allow them

to separate. So, all these points have to be considered and that is called the operating conditions.

Mode of operation is the third point. That means, should I do it in batch mode or should I do it in continuous mode. What is batch mode? You are allowing the solvent to mix with your solute and then you agitate it well and then stop the agitation, allow them to separate. Then, separate these two layers; again you introduce a fresh batch of your broth. That is called a batch mode. In a continuous mode, you are continuously sending in your feed and you are continuously sending in your solvent and then you are continuously drawing out the raffinate and the extract. That is called the continuous mode.

We will look at some designs, how where the liquid liquid extractors are operated in continuous mode. Of course, the modes have advantages and disadvantages. Continuous mode will, you will get continuously constant concentration of solute in your solvent; whereas, in a batch mode, it is going to be a batch operation. So, it is a man power intensive, it is a time consuming. So, each batch product quality may be varying. So, that is the disadvantage of the batch mode. But the batch mode can be operated at different scales; small scale, large scale; there is no problem, batch mode works very well; whereas continuous mode is ideal for very large scale operations.

Extractor type, what type of extractor should I use? Should I have a agitated extractor, should I have a non- agitated extractors; I am going to show you many designs of extractors in the subsequent slides. So, which type of extractors do we select? The next one is designed criteria. What type of a design criteria I select? Do I use mass balance? Do I use steady state mass balance relationship or do I use unsteady state mass balance relationship? Do I assume the extraction efficiency or the partition coefficient value to change from stage to stage. So, all these criteria’s needs to be considered when you select a design methodology. So, all these are the parameters you need to keep in mind when you are designing a liquid liquid extraction system.

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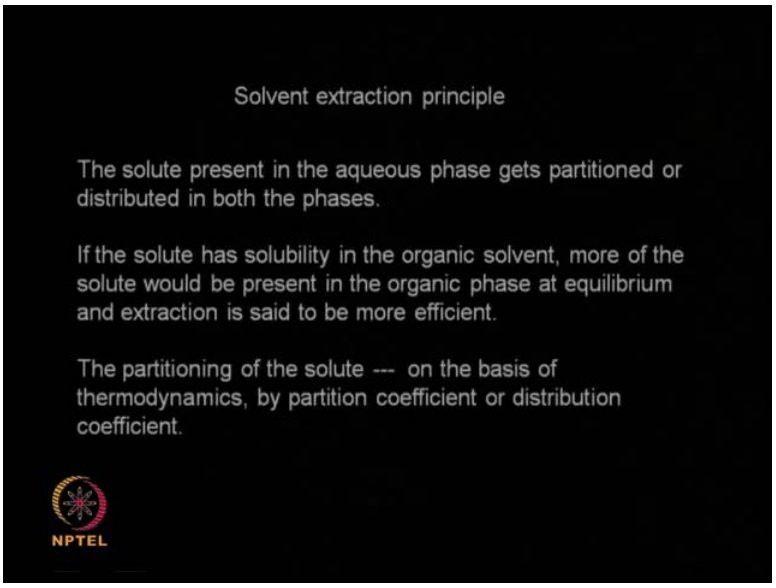

So, the principal of extraction as originally I mentioned is a thermodynamic process and it works based on the partition or distribution coefficient. So, the solute gets distributed in two different phases. So, you may have a organic solvent. So, the solute will have more solubility in the organic solvent; so, it moves into the organic phase. So, if the distribution coefficient is very very large; then, you will have a very efficient separation. The distribution coefficient or partition coefficient is not so large, you may have several stages of extraction. You may have a train of extractors and you will be and each stage you will be extracting little little of the solute. So, overall you will be extracting the entire amount of solute of your interest.

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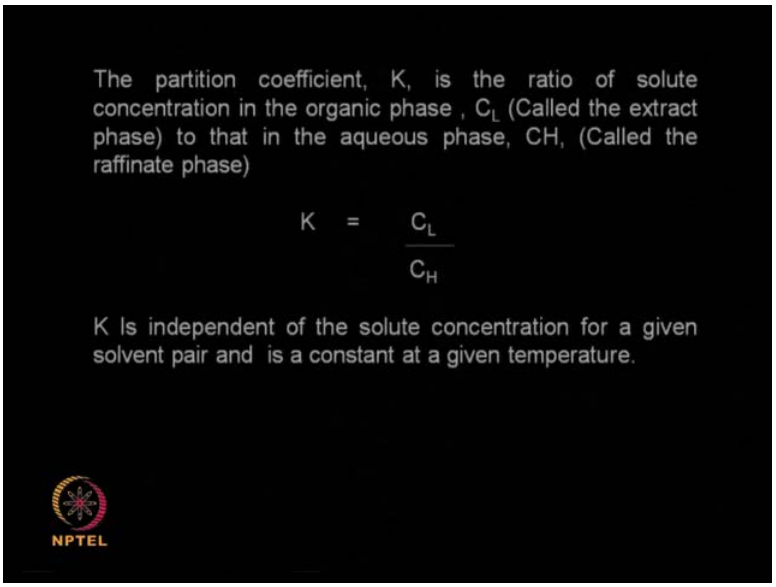

So, the partition coefficient can be defined like this. K is the ratio of the solute concentration in the organic phase divided by the concentration of the solute in the raffinate phase. So, generally concentration in the, this solvent phase will be very large. So, K will be much greater than 1; the higher the value of K, your extraction process is very very efficient.

The assumption here is it is independent of the solute concentration for a given solvent pair. That means, if I have a particular solvent which I decide and the broth K should be constant. It should not depend on the concentration; whether I do the extraction for recovery of a 1 milli mole concentration of solute or if I do the extraction for 1 micro mole k should be constant; it will, it should not change; so, that is the assumption here.

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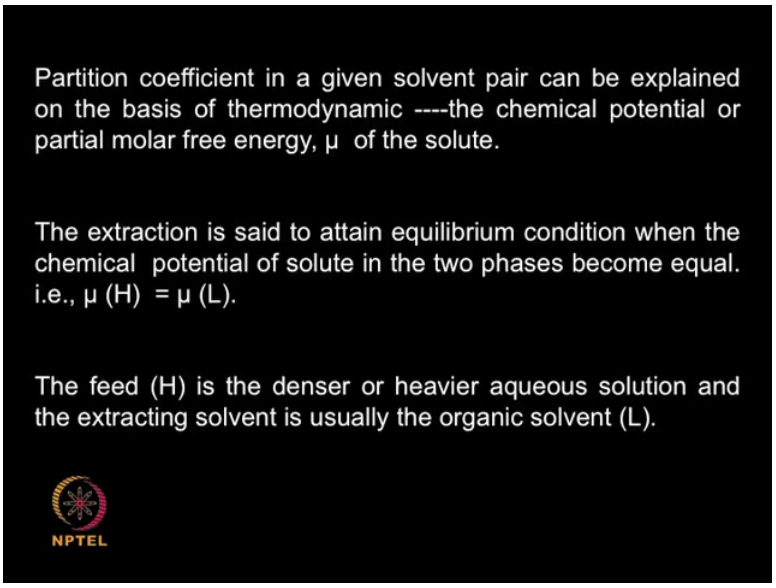

So, it is basically based on thermodynamics; that means, it is basically depending on the chemical potential or partial molar free energy. So, the term that comes into the picture is the mu; mu is the chemical potential. So, you are adding your feed and you are adding your solvent, mixing it thoroughly and then you are separating two different streams from the stage.

So, that the two streams that are leaving the extractor are suppose to be in equilibrium; that means, they attain equilibrium. So, when they attain equilibrium the chemical potential of the solute in these 2 phases will be equal. So, that means mu H is equal to mu L; L is your light phase or the solvent phase, H is the heavy phase or the broth, fermentation broth phase. So, the chemical potentials have to be equal.

So, main assumption here is the two streams that are leaving the extractor attain the equilibrium; that is an ideal condition. But generally sometimes we do not give enough time for the solute to partition effectively and reach an equilibrium. If the viscosities are very large then the movement of the solute molecules from the heavy phase to the light phase takes longer time. But I might not wait for such a long time; so, they actually do not reach a equilibrium.

But for design purposes or calculation purposes, we can assume that the chemical potentials of the streams leaving the extractor reach a equilibrium, that means, they are equal. Another important point we assume is generally for notational purposes we call

the feed as the density, denser or heavier phase and the solvent as the lighter phase. But it does not matter sometime solvents can be very heavy like your chloroform. But generally we assume for these sort of explanation purposes. So, in a thermodynamic situation the chemical potentials are equal; that means, the system has reach a equilibrium.

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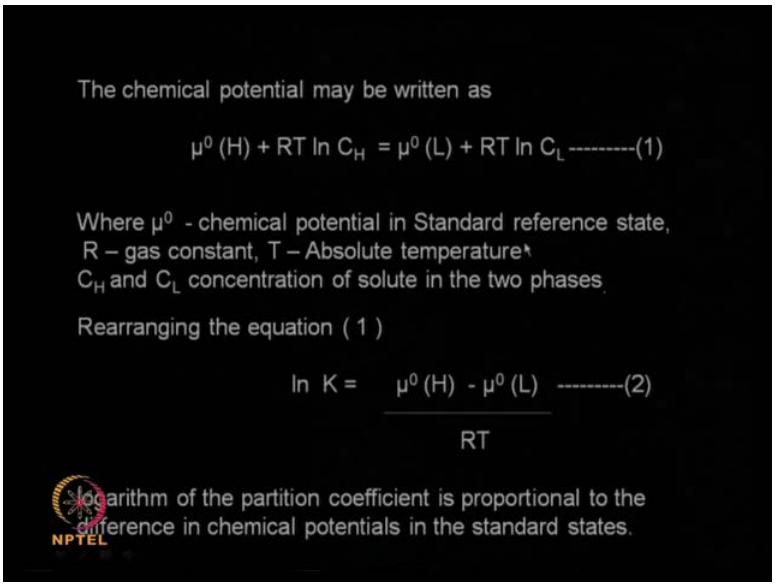

So, the chemical potential mu H can be written as mu naught H plus RT Ln C H. That is the concentration of the solute in the heavy phase; this is equal to again mu naught L plus R T ln C L. That is the concentration of the solute in the solvent phase or the lighter phase. Now, mu naught is called the chemical potential under standard reference state. As you know in thermo dynamics, we always make our calculations starting from a standard reference. So, that is why we call it mu nought and R is the usual gas constant and T is the temperature.

So, we can re arrange this equation and we can get a relationship for ln K. ln K will be equal to mu naught H minus mu naught L divided by RT correct. And, as you know K is nothing but C L by C H as I defined in the previous slide. So, logarithm of the partition coefficient depends on the chemical potentials of the heavy and the chemical potential of the light at standard condition. And, the temperature will come in the denominator. So, K if I take then you will have e power minus just like an irenous type of relationship, you are going to K.

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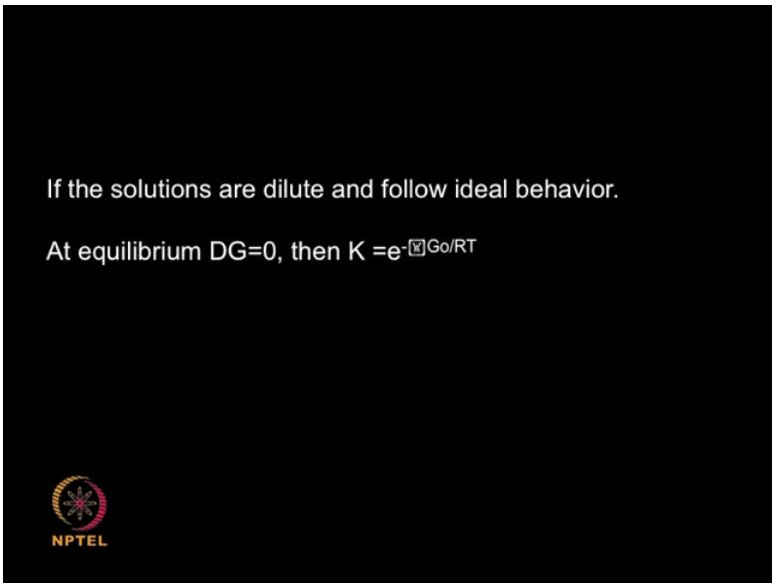

So, at equilibrium delta G is equal to 0 for a dilute conditions and ideal conditions. So, K will be equal to e minus delta G 0 divided by R T. So, K depends on temperature just like an irenous equation for Rate of reaction. Where, there also we have a exponential raise to the power with the temperature term coming into that actually. If you remember the irenous equation for reaction, K also looks exactly similar to that, correct.

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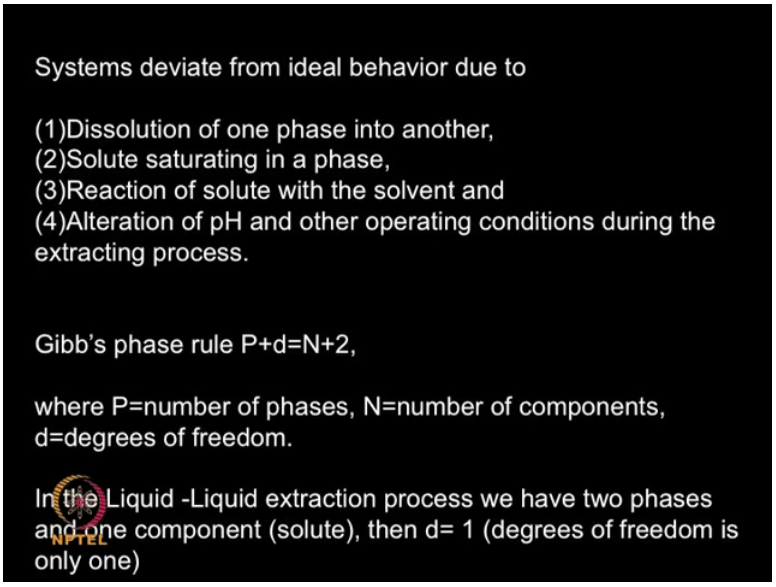

Now, of course, systems deviate from ideal conditions, no system is an ideal; because in a real situation you are going to extract a solute from a fermentation broth. So, you are

going to have many species, you are going to have solids present, you are going to have a highly viscous broth, you are going to have a biomass present. And, then the extraction process, you do not leave it for a very very long time; so that, the solute in both the phases come to equilibrium. So, it is a non-ideal situation. And, on top of that you are also going to have disillusion of one phase into another. For example, if I take a alcohol to extract something a solute from a aqueous medium, alcohol may be soluble in the aqueous medium.

Solute saturation in a phase, because a solute many solute will have certain saturation solubility. So, at that particular concentration condition, it may have a non -linear type of behaviour. Reaction of solute with the solvent; sometimes some solutes will start reacting with the solvent. Then, you cannot just assume there is a partition alone is taking place; there could be a reaction also taking place.

Alteration of pH and other operating condition during the extraction process; of course, the pH is going to change. Sometimes, temperature may change because when you take a cold solvent and use it to extract a solute from a hot fermentation broth. So, these operating conditions also will affect my extraction process. So, you will not have this type of a thermodynamic equilibrium taking place actually. So, you need to consider that in reality there is non ideality which is taking place and the streams leaving the extractor is not in equilibrium.

Now, the Gibbs phase rule says that P plus d is equal to N plus 2. Where P is the number of phases, N is the number of components, d is the number of degrees of freedom. So, what do we have? We have two phases, we have the we have feed phase and we have the solvent phase; two phases. Now, component wise we have one component; that is your solute. Solute is getting portioned either in the solvent phase or it is present in your feed or fermentation broth.

So, if you substitute that you find that the degrees of freedom d is equal to 1. So, you have only one degree of freedom. So, the concentration of the solute in the solvent phase is known; then, automatically the concentration in the fermentation broth or feed is fixed. So, there is no extra degree of freedom there is only one degree of freedom for this type of liquid liquid extraction. So, you see the thermodynamics play a very very important

role in this process and the phase rule determines the number of degrees of freedom that are present for this extraction process.

So, if once you fix the concentration in the solvent phase, automatically the concentration in the feed phase is fixed or if you know the partition coefficient automatically both the concentrations are fixed. That means, if you know the partition coefficient the concentration of the solute leaving the stage in the solvent phase and in the raffinate are fixed; there are no more extra degrees of freedom after that.

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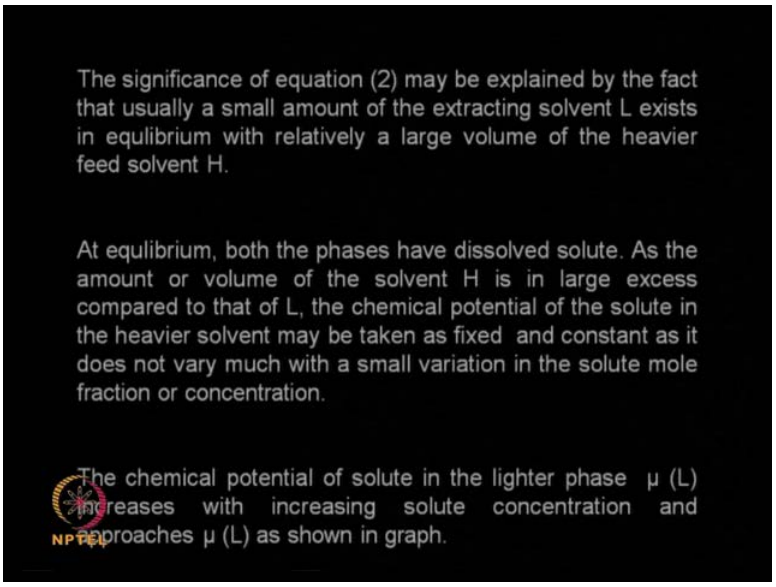

So, it is the thermodynamic always work under very dilute conditions; it will not work at very concentrated condition. And, at equilibrium both the phases have the dissolved solid and the amount of volume of the solvent H is in. large excess compared to that of the L. That means, you always use a very small amount of solvent to extract your solute; whereas your feed may have a very very large quantity.

So, the concentration chemical potential of the solute in the heavier solvent may be taken as fixed and constant. And, it does not change very much with small variation in the solute mole fraction or concentration. Another important point is the chemical potential of solute in the lighter phase that means mu L increases the increasing solute concentration. So, it will keep on increasing and it will finally reach a saturation.

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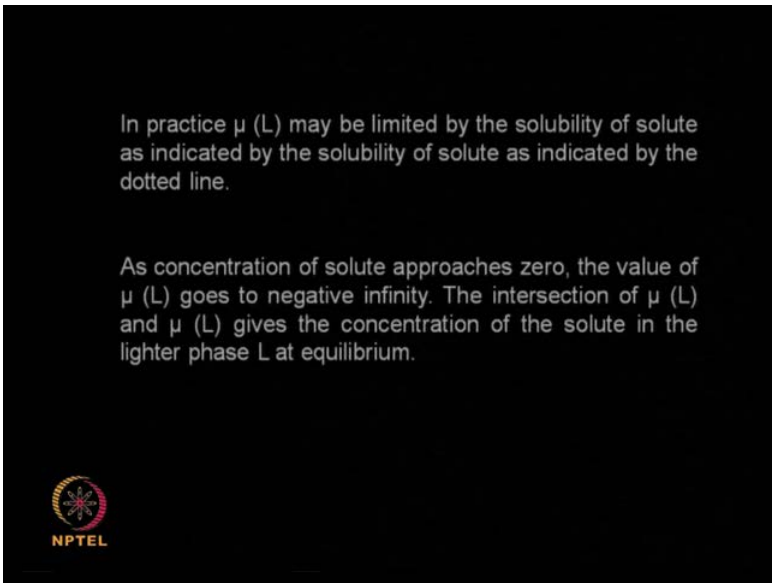

But mu L cannot keep on increasing add infinite term because there is a limitation on the solubility of the solute. And, beyond a certain value no more solute can dissolve into your solvent phase.

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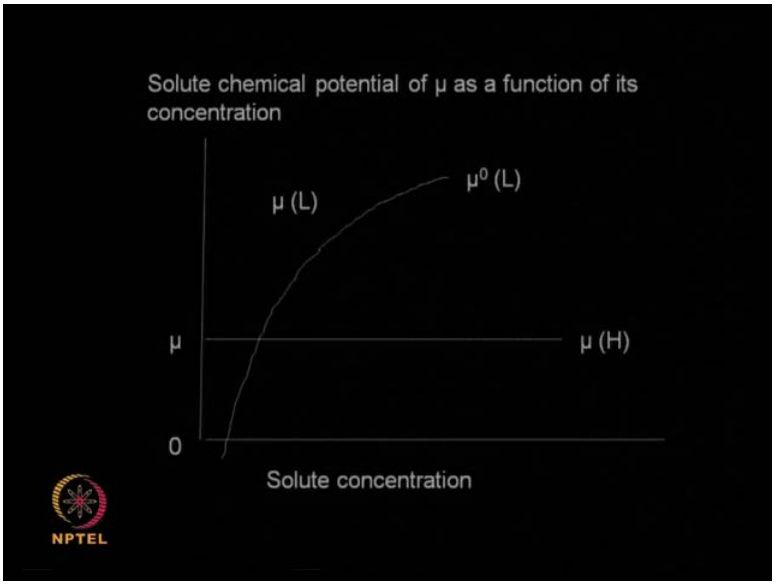

So, what will happen is you will have the chemical potential of the solute in the heavies that is given by this. And, then a chemical potential mu L keeps on increasing actually until it has to saturate out; because the solubility of the solute in the solvent is fixed. And, that determines the amount of solute that moves into your solvent phase.

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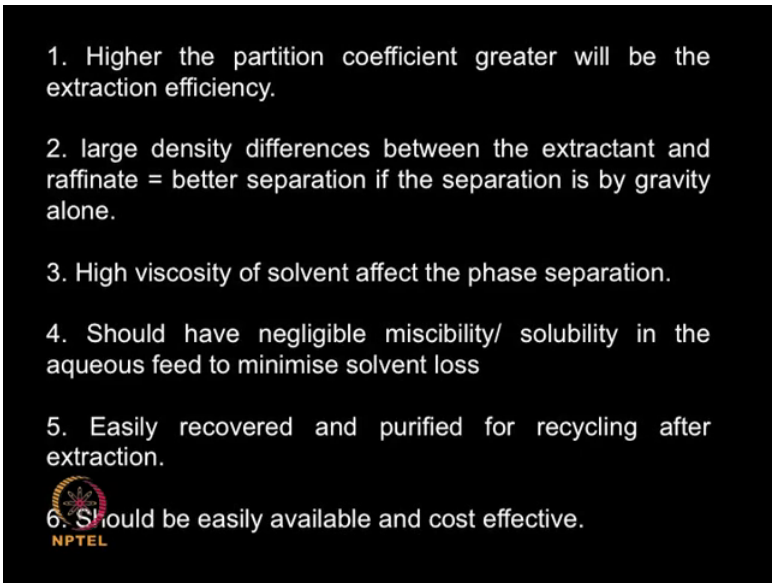

So, there are many other points which needs to be considered when you are performing a liquid liquid extraction; higher the partition coefficient greater will be the extraction efficiency; here very large number means extraction will be very good. Large density difference between the extractant and the raffinate you can achieve good separation using gravity alone. That means, after the mixing you can allow them to settle from each other.

So, there could be a separation you will get a very nice phase separation because of gravity. But if the density difference is smaller then you may have to resort to some sort of a centrifugal separation; high viscosity of the solvent affects the phase separation. Because as I said you are fermentation broth will be highly viscous because of cell, debris, bio mass and other portentous material which have come out of your broken cell. So, they movement of the a solute from the heavies into the light is very very slow.

Next point there should not be a miscibility of the solvent into the heavies and vice e versa; otherwise you are losing some of the solvent into the heavies which is lost actually. So, the idea is you have to minimise the solvent loss. Now, you should be able to after the extraction remove the solvent from the solute which has been which has being used for extracting actually. Because your solvent has to be purified and again recycled for further extraction. Because the cost applies a very very important role in your downstream of and the solvent recoverability is a main issue in the overall

operating cost. The solvent should be easily available we do not want to use many exotic solvents because then it may be very expensive. And, it will add to the extraction cost.

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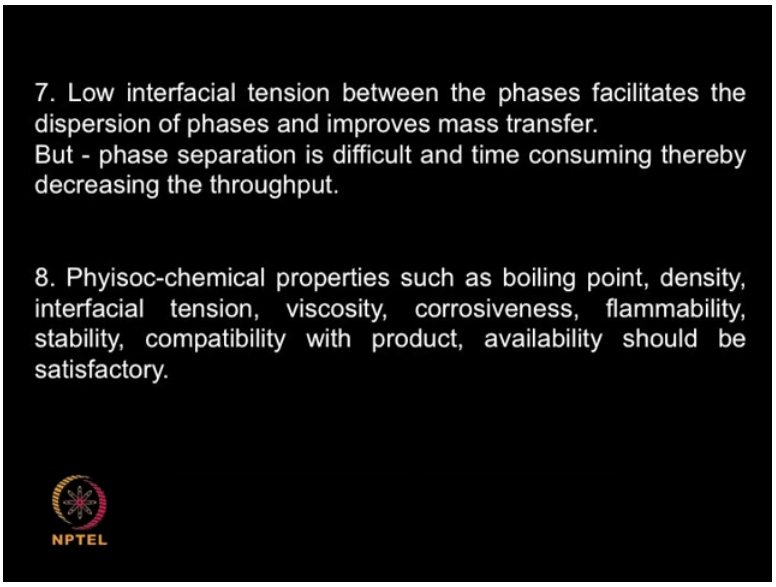

The if you have a very low interfacial tension between the phases then disposition of the phases is growed and it also improves the mass transfer. But then if you have the low interfacial tension then the phase separation becomes difficult; the phase separation takes much longer time. So, the separation will be taking very long time. So, hence your overall throughput also becomes very very low.

The physico chemical properties of the solvent like the boiling point, density, interfacial tension, viscosity, corrosiveness of the solvent, flammability of stability under operating condition compatibility with the product, availability should be satisfactory. So, you have a large number of requirements while selecting a solvent. For example, it should not be corrosive to the material of construction of your extractor; it should not be a flammable.

That means, you should not use solvents which are highly flammable are very have very low boiling point. Because lot of solvent will vaporise during your handling and you will be losing solvent as a vapour. And, also you will be having possible explosion hazard or flammable hazard if the solvent goes into vapour phase. Solvent should not de activate your metabolite or protein of interest. So, it should be compatible with the product. So, we need to select the solvent which satisfies all these conditions.

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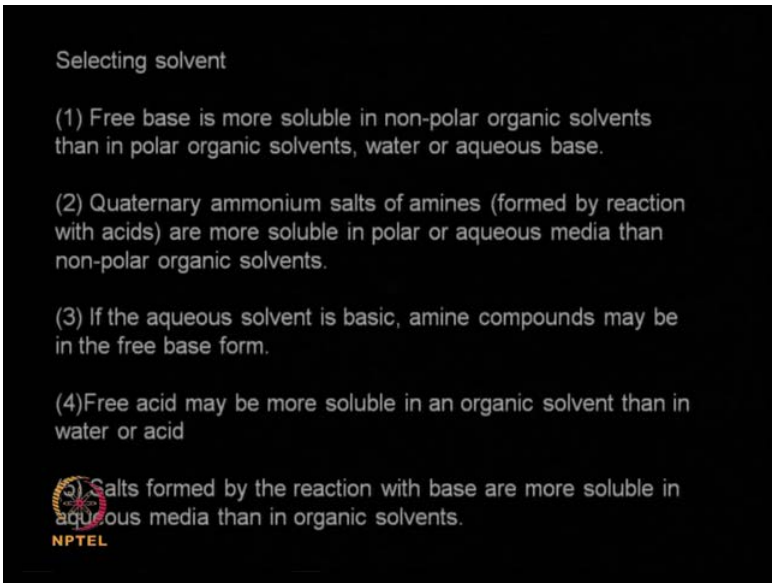

So, selecting solvent plays a very important role and it depends on the type of product which you are trying to recover number one; it depends on the pH conditions of your fermentation broth. And, it depends on whether it is aqueous or a non aqueous situation. For example, free base is more soluble in non polar organic solvents than in polar organic solvents like water or aqueous base. So, you need to keep that in mind; quaternary ammonium salts of amines formed during reactions are more soluble in polar or aqueous media than non polar organic solvents.

Because it is a salt and it is a quaternary ammonium salt. So, it will be stable in polar or aqueous solvent; if the aqueous solvent is basic amine compounds may be in the free base form, free acids may be more soluble in an organic solvent than in water or acid. Salts formed by the reaction with base are more soluble in aqueous media than in organic solvents.

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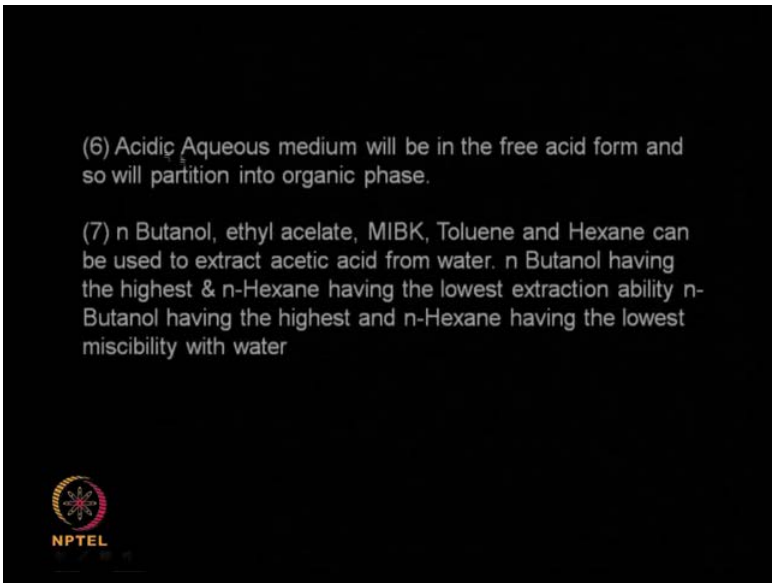

Acidic aqueous medium will be in the free acid form and so will partition into organic phases. So, all these points tell us the pH determines what type of solvent to use; if there are salts present you have to select a suitable solvent at an appropriate Ph. So, that your compound is stable and it does not loose stability during the extraction process. Now, if you have acetic acid in water if you want to recover that; n butanol, ethyl acetate, MIBK, toluene and hexane can be used to extract acetic acid; n butanol will be having the highest and hexane will be having the lowest extraction ability. Because n butanol has having the highest and hexane having the lowest miscibility with water.

So, when you have a group of solvents each solvent looks a feasible opportunity for extracting your solute within that group you can select based on the miscibility's, based on the extraction ability as well. Now, as I said if you take a fermentation broth it may have several metabolites. And, most of the time when you are using a solvent to recover one metabolite more than one may also get extracted during the process.

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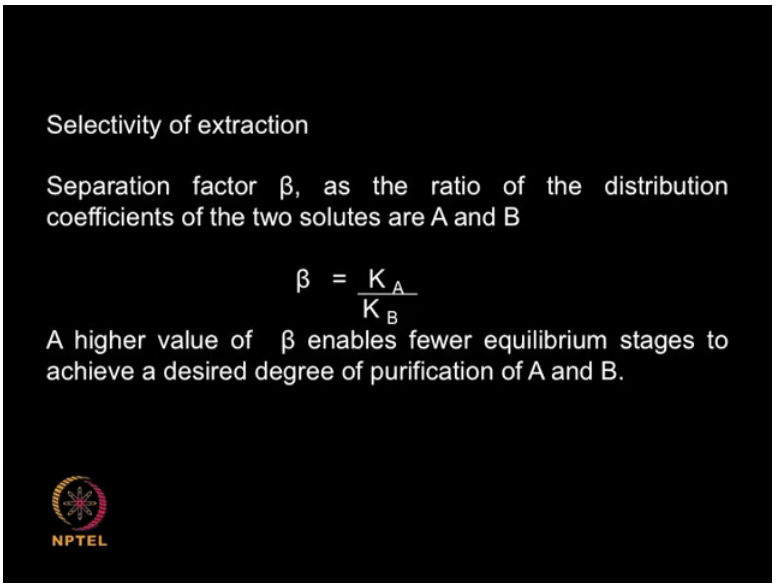

So, there is something called the selectivity of extraction. So, if you have 2 metabolites A and B and you are using a solvent to extract A and B also may get extracted. So, the ratio of K A divided by K B; that means ratio of partition coefficient for the solute A divided by the partition coefficient for solute B that tells you the selectivity of extraction. That means, how much more of A I will be able to extract than the amount of B. If a KA and KB are almost equal then my beta will be almost equal to 1. That means, when I am using this solvent for extraction I will be extracting both A and B. Then, later on I may have to separate again A and B; if I am interested only in the A then B is a wasteful product which is also getting extracted.

So, I need to select a solvent which will have more selectivity towards A than towards B; that means K A should be much larger than K B. So, that all though I will extract some B in during the extraction my predominantly the solvent will contain only A. So, it is not only that the partition coefficient has to be very large. But the ratio of partition coefficient for A and B that is K A by K B also should be large. So, that my selectivity towards A is also large.

So, that is a big problem especially when we have several metabolites present from a fermentation broth. Because I will be having several partition coefficients I may have K A, K B, K C, K D and so on. So, many of these metabolites may be getting extracted during the process and I may have to look at K A by K B or K A by K C, K A by K D, K

A by K E and so on; and look at the selectivity terms and decide on a suitable solvent. So, that is again a very challenging task. And, similarly, if I have many proteins and my solvent is picking up all these proteins. Then, I need to select a solvent which will be more preferential towards A than towards protein B or protein C or protein D or I may have to do these extraction and later on go to a chromatography type of situation to just pick out the protein of your interest.

We are going to talk about chromatography later on and you may resort to different types of chromatography and that point. So, initially you will go for a solvent extraction and in the process you may extract many proteins. And, then you go to a typical chromatography which will extract or which will just pick up only the protein A from a mixtures of protein. So, your downstream may have a extraction and then you may have a chromatography; if it is metabolite than you will have an extraction.

Then, if the metabolites are stable at a different temperature conditions I may go to distillation where you may separate out A, B, C from one another. So, for a protein you may have extraction followed by chromatography or chromatography's for a metabolites small molecule which is stable at different temperature conditions; I may go to extraction followed by distillation. Because distillation is always cheap as long as your metabolite is stable at all conditions you may resort to distillation rather than going to chromatography. So, the selectivity term the separation factor beta is also very important when you decide on the solvent.

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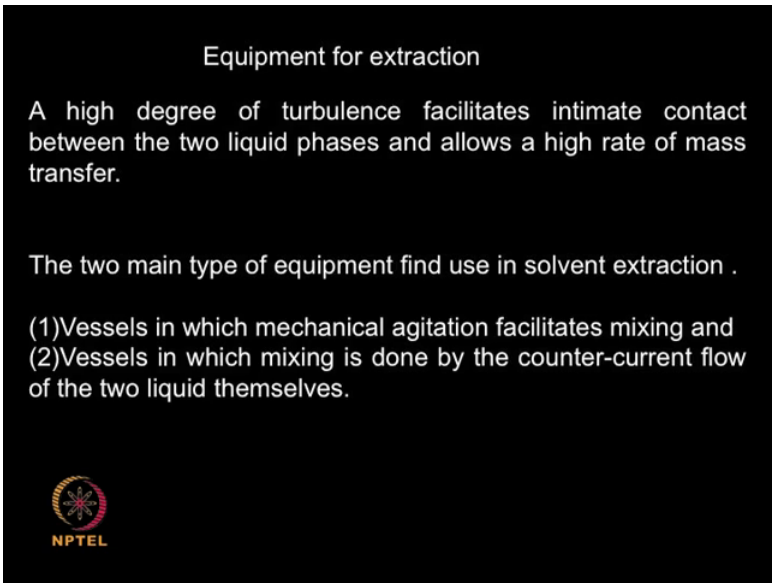

There are many equipment's used for extraction in your lab no problem you will have something called a separating funnel; you take your broth you add some solvent mix them and then a leave it for separating. So, a separating funnel will be slowly tapering down with a bottom discharge. So, after mixing them thoroughly you will allow them to separate out into 2 layers. And, then the bottom layer you remove it by opening a cork which is located at the bottom of your separating funnel.

So, all the labs we always have a separating funnel which is tapering downward. But in large scale operation you may have to resort to many different types of mixing separating systems. Because of many problems which we said because of non ideality, because of the viscosity conditions and you want to do this entire operation very fast. So, the mass transfer limitations the movement of the solute from the heavy to light needs to be speeded up.

So, you need to create a turbulence between the 2 different liquids. So, that the solute moves very fast from the heavies into the lights. So, it is not only the thermodynamics you are also wanting to improve or speed up the kinetics; 2 types of equipment's predominantly used are equipment's which have mechanical agitation making equipment's which do not have an agitation mechanical agitation. But there is a counter current intimate mixing between the 2 phases which creates the turbulence and mass

transfer movements; we will I will show you some pictures of many equipment's which are used in industrial scale liquid liquid extraction process.

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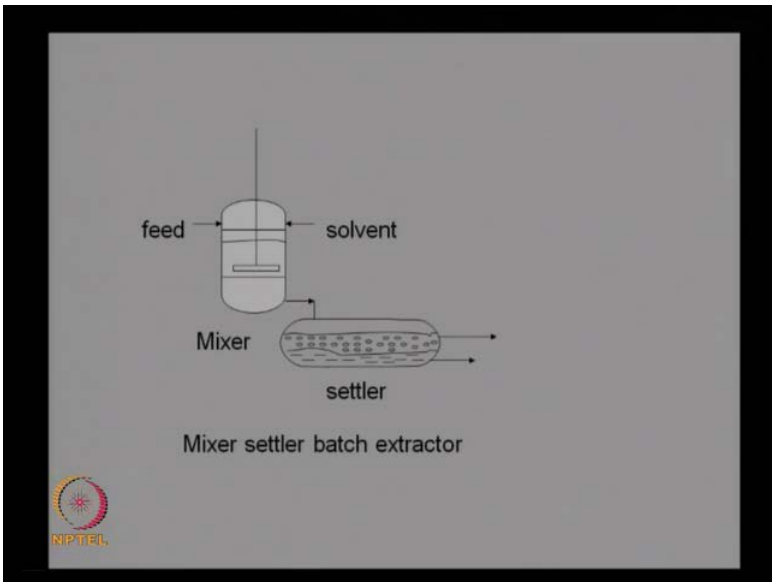

A simple batch type of situation which is called a mixer settler batch extractor; you have a mixer, you have a settler; in the mixer what do you do? You add your feed, you add your solvent close down mix it thoroughly create good intimate contact. And, afterwards what do you do you discharge the whole thing in a settler you allow them to phase separate into the heavy phase and the light phase; your solute may be here if your solvent is light solute may be here predominantly if the solvent is heavy.

So, then you leave it for several hours until the phase is separate and then you discharge the bottom with discharge the top. And, then if you have the fermentation broth again you may carry out one more mixer settler; again you can put it here you can take another fresh solvent here again a allow it to come in contact with each other; again you can do a mixer settler.

So, you can have a series of mixer settlers a train of mixer settlers possible. So, this is called a batch operation and the mixer settlers are very easy to construct. So, you need just 2 tanks; one tank will be agitating other tank will be non agitating where you allow the phases to separate into 2 distinct layers. But there is always as I said non ideality comes into picture. So, the interphase between the 2 layers may have some solids which has precipitated out; it may have a combination of both these a phases; you may have a

the little bit miscible solvent into the heavies. So, the middle portion will not be very very sharp; there could be another layer which needs to be disposed of. This is a batch operation you can have several types of continuous operations.

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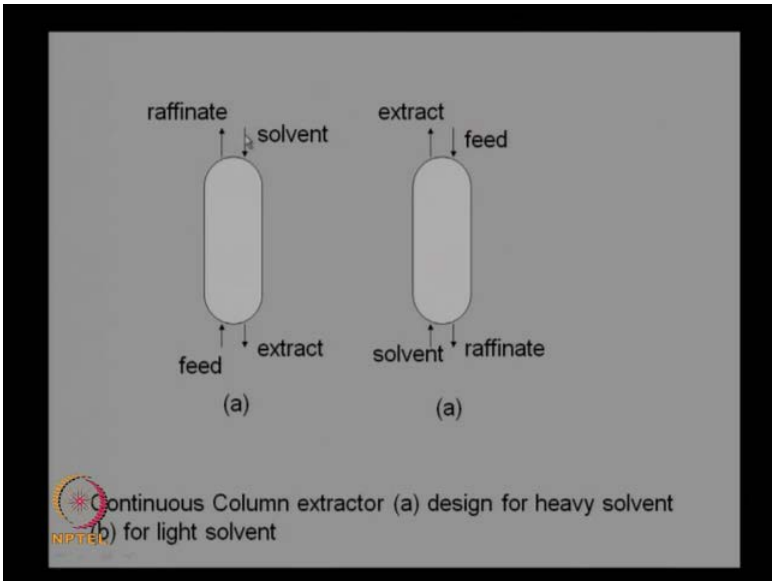

You can have something called the system counter current type of situation where the solvent flows in one direction your feed flows in another direction. If your solvent is heavy then you add the solvent from the bottom I mean top and it comes down it picks up your a solute it extracts your solute. So, it comes out as a extract. And, your feed travels upward and comes out as a raffinate; the feed will have less of your solvent; for light solvents you introduce the solvent from the bottom it rises up your feed is heavy relatively heavy; then the solvent the feed travel down.

So, the extract comes at the top. So, this is 2 different continuous column extractors one for the heavy solvent and one for the light solvent. Now, the internals of this columns can be very very different; you can have different types of internals like in distillation column; I will show you pictures of few of the possible internals. Because you want the solvent and the feed to come in good contact you need generate turbulence. So, that there is a mass transfer of the solute from the heavies goes into the lights. So, you need to create a very high mass transfer rate.

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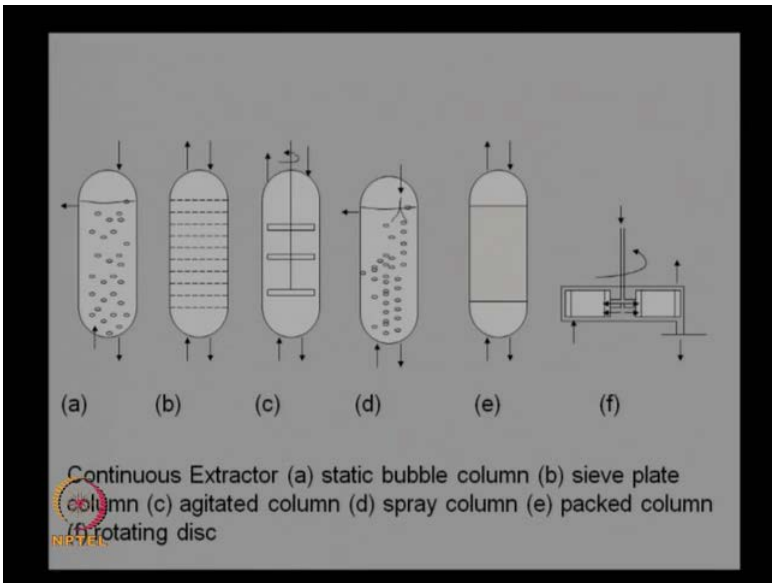

There are a large number of continuous extractors as you can see from this picture; this is called a static bubble column. So, you have a one liquid which is static it creates a large tall height; the other liquid is introduced in the form of a bubbles. So, there is a mass transfer and the interphase between the bubble and the bulk of the liquid; where the solute moves from one phase to the another phase; the mass transfer in such situations are bit low.

The next design you is called the sieve plate column. So, you have many plates which perforations. So, when the liquids travel a one going from the top to bottom other going from bottom to top. And, because of this sieve plates there is going to be some turbulence created and there is a mixing taking place in each portion of this sieve plate. So, this called a sieve plate design.

The third design is agitated column. So, you have a tall column and you have a agitated with many blades. So, the agitator rotates so at each level there is a mixing taking place between the 2 phases. And, there is a intimate contact and mass transfer takes place. The fourth type is called the spray column; that means a one of the liquid is sprayed this liquid can be your solvent or it could be the heavies it is sprayed. And, again it creates a fine bubbles when you create a fine bubble the mass transfer area is very large; as you know a mass transfer area plays a very important role in kinetics of extraction. So, finer

the bubble more is the mass transfer area. So, higher is the rate of extraction; fourth design is called a packed column design here you have a column with inert packing.

So, as the liquids travel because they move through the packing; there is a intimate mixing the packing acts as a location for the 2 liquids to come in contact with each other; it provides an surface area for the 2liquids to come in contact. And, the transfer of the solute from the heavies to the light takes place. The fourth design is called the rotating disc.

So, you have very fast disc rotating and the one liquid is introduced from here other liquid is introduced from this side. So, this liquid because of the centrifugal action is thrown out and this liquid which is introduced here; when these liquid is thrown out at very large g values they come in contact large mass transfer is created. So, there is a mixing taking place and the mass transfer of the solute takes place actually.

So, the force with which the liquid that is introduced here hits the other liquid creates a large turbulence. And, creates the necessary mass transfer for the transfer of the solute from the heavies to the light; when compared to things like bubble columns and spray columns the interaction that is created in rotating disc is much higher because of the centrifugal force of one of the liquid. So, there is a much better intimate contact and the rate of mass transfer is also much higher. So, these are all called centrifugal separators. So, centrifugal separators are used if the density difference between the 2 liquids are not very high.

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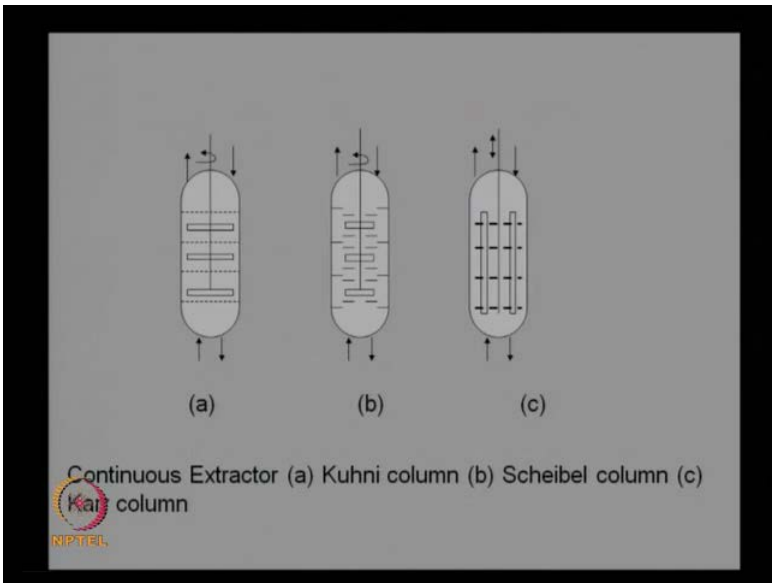

Then, there are other designs the first one is called the Kuhni column, second is called the Scheibel column, the third one is called the Karr column. So, in Kuhni column you have agitators as well as you have sieve plates. So, each region between 2 sieve plates acts as a single stage extractor. And, there is a good mixing inside this stage because of this agitator blade. So, when you have many sieve plates and many blades you are creating automatically several stages; where in each stage there is a mixing of the liquid and the heavies. So, you can move the solvent from the bottom up or from top up depending upon the density of the solvent with respect to your fermentation broth. The next design this is called a Scheibel column.

So, instead of sieve plates you are partitioning the column into several stages; again the principal here is you are creating several stages next to each other. So, the 2 liquids come in intimate contact in each of the stage separately whereas, in your Kuhni column you are using sieve plates. Here, you are using certain partition baffles to create this stage effect. The third type is called the Karr column where the agitator moves up and down. So, when the agitator moves up and down the blades also move up and down. So, they create a turbulence and brings in a intimate contact between these 2 liquids.

So, you see a large number of designs using mechanical or using a non mechanical type of set up; where you are trying to bring in a good degree of contact between the 2 liquids. So, that you can improve the rate of mass transfer of the solute from the heavy to the

light that means solvent. So, from the feed to the solvent layer because the rate of mass transferred determines how long you can do this extraction process. And, if you want to improve the throughput or you want to increase the throughput the rate of mass transfer has to be very very high.

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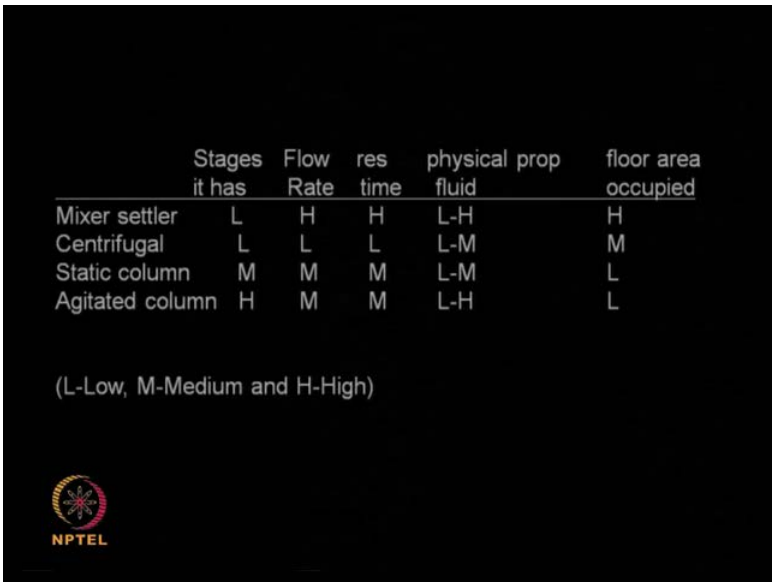

Each of these designs have a advantages disadvantages; this table gives you some idea of the advantages disadvantages of each one of them. So, one important thing is number of stages present in each one of this design the flow rate that means the throughput; what is the residence time, what type of physical properties fluid that can be used and what is the floor area occupied? Floor area occupied is also very very important. Because if you have the extractor spread all over the floor then you are using up too much of the area plant area whereas, if the extractor is vertically placed then you are occupying less floor area which is advantageous. Because more floor area, more space you will require more space you need to spend money on buying that space. If you take mixer settler it does not have many stages. So, it is very low L means low floor rate can be high I can have very large mixer settlers.

So, I can process large amount of liquid; residence time is also very high because I will do a mixing for a long time. And, then I will do a settling for a long time; physical properties I can use different types of fluids, different types of fermentation broth to carry out this particular operation floor area occupied will be very high. Because I will

require some space for the mixer, I will require some space for the settler. So, you see many disadvantages. Centrifugal separator it does not have many stages; flow rate also has to be low, residence time is low so that is good; floor area occupied is much less when compared to a mixer settler.

Whereas, if you go to a column extractor that is vertical column, static column, agitated column we saw a large number of columns. If you look at static column it has some number of stages flow rate is medium, residence time is medium; the floor occupied is very low. When you have agitated column it has many stages like I talked about some of these Karr column and so on or sieve plate column, Scheibel column all these columns they have many stages possible.

And, each stage can act as a single ideal thermodynamically ideal unit where there is a intimate contact between you are a solvent and the feed; flow rate can be medium, residence time can be medium, floor area occupied is very minimal. So, the columns design occupy less space. And, if you look at agitated columns then it also has a large number of stages; that is why industrial scale operations are always done in agitated columns rather than mixer settlers.

Mixer settlers are very cheap I just require 2 tanks but it has got lot of disadvantages when compared to say an agitated column; where the design needs to be properly organised. But it has many advantages when compared to the mixer settler. Centrifugal also has a few advantages but the number of stages are minimal. So, I may have to have 2 or 3different types centrifuges; if I want to perform a centrifugal type of separation.

Static columns are good it does not require any mechanical agitation; that means you do not require motors for agitating your column. But the number of stages are much less when compared to agitated column. So, that is the disadvantages of static column but the main advantages I do not require a mechanical agitator. That means, I am saving on not only the purchase of motor and agitator but I am also saving on electricity; if I want to operate a motor which I need to utilise if I have a agitate column. So, each of these design has advantages disadvantages and as I said generally now a day industries prefer agitated columns. Because of several advantages when compared to several other types of design; we will stop with this.