Principles of downstream techniques in Bioprocess – a short course
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Lecture – 7
Liquid-Liquid Extraction

In this class we are introduce the liquid-liquid extraction and I will take one more class on the liquid-liquid extraction on top of that later on I will also talk about two phase, aqueous extraction, reverse micelle extraction because extraction is one of the most important downstream steps. So we need to spend more time on that especially for bio-molecules like proteins, carbohydrates, we cannot use distillation or any other harsh approaches.

So liquid-liquid extraction is the best way of doing things because you are doing at mild conditions almost buffer pH and the temperature will be at room temperature so..
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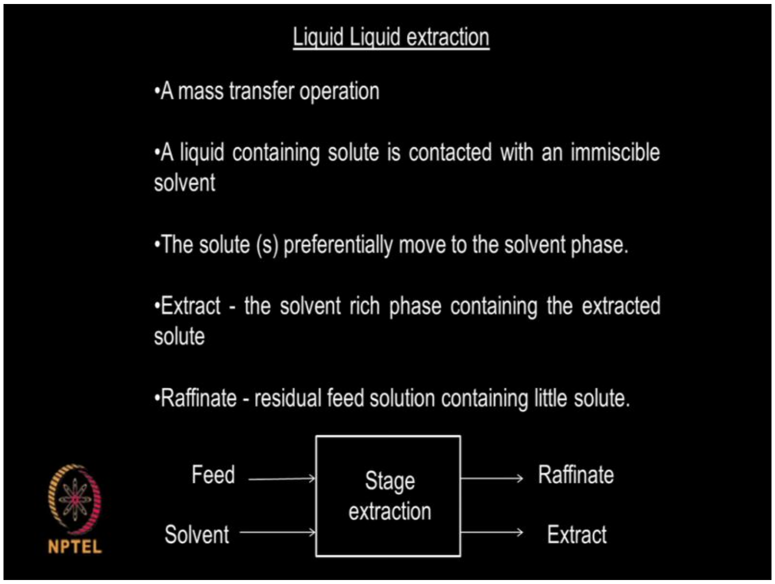

Liquid Liquid extraction

- A mass transfer operation
- A liquid containing solute is contacted with an immiscible solvent
- The solute (s) preferentially move to the solvent phase.
- Extract - the solvent rich phase containing the extracted solute
- Raffinate - residual feed solution containing little solute.

So what does extraction indicate? It is a mass transfer operation a liquid. There are 2 liquids, we have solute in one liquid okay and that gets moved or transferred into the solvent phase and both these phases have to be immiscible. That is very very important. The solute in the heavy phase, it is called or sometimes it is called feed phase and the one the solvent is into which the solute get moved. So this is a mass transfer operation, so we have the feed.

We have the solvent, the solvent can be heavy solvent with respect to the feed or it can be a light solvent with respect to the feed and then once the extraction is done in a stage, the feed is known then becomes called raffinate and this is called extract. So hopefully the extract will contain more solute than it contained in the beginning. So sometimes we introduce very fresh solvent, sometimes we introduce used up solvents and there is an equilibrium which takes place between the feed and the solvent. and the solute gets partitioned.

That is the term we use, it gets partitioned into the extract phase okay. And then later on we can remove the solvent by simple distillation, thereby you get your solute. So this is as I said, this is very important downstream operation, which is practiced for extracting metabolites, small molecules and proteins like I said, we have this two phase aqueous extraction and reverse micelle extraction, whereas even proteins or bio molecules enzymes could be extracted.

So the solvents that are generally used are like ethyl acetate, chloroform, methanol and so on actually and this is called as stage extraction one stage. So you can have second stage, third stage, fourth stage and so on, so that you could extract as much as the solute as possible using solvent, as I said the solvent could be fresh or it could be used solvent. That means it may contain some solute into it actually. So this is called an equilibrium operation and this is called a mass transfer operation. So we need to remember that.

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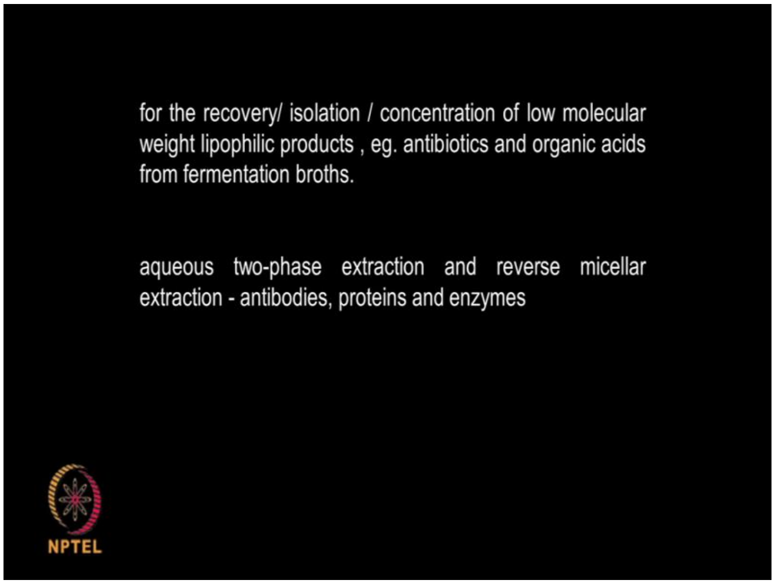

for the recovery/ isolation / concentration of low molecular weight lipophilic products , eg. antibiotics and organic acids from fermentation broths.

aqueous two-phase extraction and reverse micellar extraction - antibodies, proteins and enzymes

So we can use this for recovering antibiotics organic acids lipophilic products low molecular weight lipophilic products and if you are interested in proteins enzymes antibiotics bio-molecules then we have to resort to 2 phase extraction or reverse micelle extraction so in 2 phase and reverse micelle generally you have water as the extraction medium and as you know proteins and enzymes are more stable in water or the buffer so we do not resort to solvent extraction. Solvent extraction is generally for a large molecules, small molecules, metabolites and so on actually.

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The advantages of solvent extraction

- Selectively extract from fermentation broth or from reaction medium in the case of biotransformations
- Ambient conditions-so stability is not an issue
- Suitable over a wide range of scales of operation.

So what are the advantages? You can selectively extract from a fermentation broth, so after if you do a filtration or solid-liquid separation, the concentration of metabolite may be very very low. So you need to build up to may be 40 % or 50 % okay, so it is called recovery and extraction is normal procedure and it is very cheap to do. It is generally ambient condition, so stability is not an issue. It is suitable for a wide range of scales, even in your lab, you can do an extraction.

And even in large scale when we talk about thousands of litres of manufacturing scale, we can have extraction. So that way it is suitable for even a very large scale of operation, starting from milliliter or cc going right up to tones of material that can be extracted using a solvent. So you can have one stage, you can have multiple stages of operations okay. You can have cross flow type of extraction, you can have counter-current type of extraction and we will talk about each one of them little bit okay.

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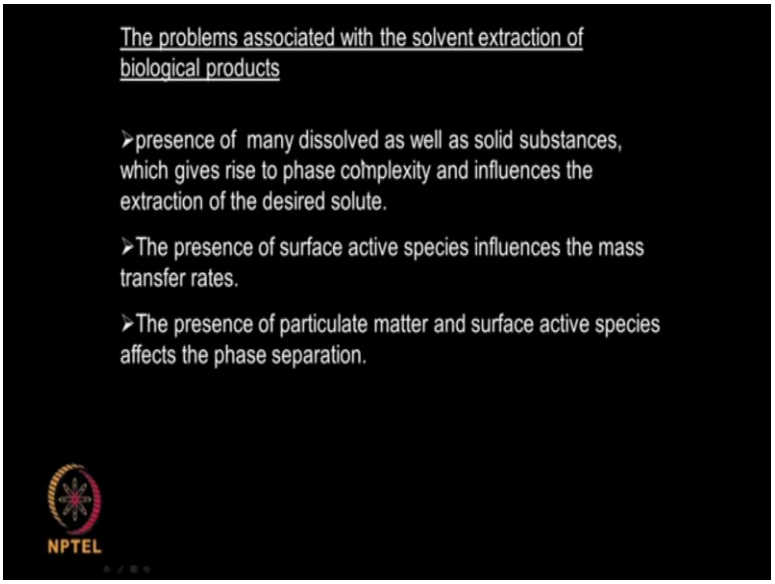

The problems associated with the solvent extraction of biological products

- presence of many dissolved as well as solid substances, which gives rise to phase complexity and influences the extraction of the desired solute.
- The presence of surface active species influences the mass transfer rates.
- The presence of particulate matter and surface active species affects the phase separation.

So the problems associated with solvent extraction, sometimes you may have many dissolved solid substances, so you will not be able to get a good phase separation, there will be a complexity of the phases, so the extraction of the desired product becomes difficult, there could be some surface active agents like surfactants, that may be present in your fermentation broth. So the mass transfer becomes a problem because there could be a small layer between these 2 heavy layers as well as the solvent layer which may be preventing the transfer okay.

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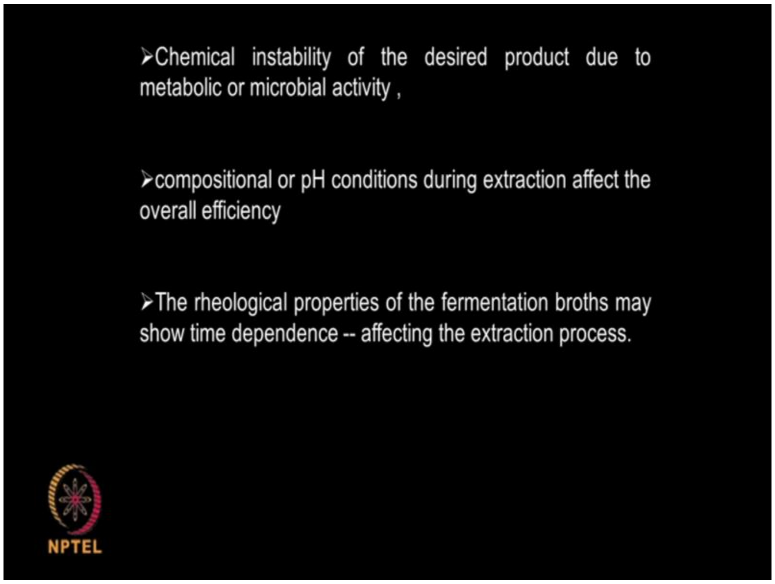

- Chemical instability of the desired product due to metabolic or microbial activity ,
- compositional or pH conditions during extraction affect the overall efficiency
- The rheological properties of the fermentation broths may show time dependence -- affecting the extraction process.

There could be particular matter, which may be preventing the separation phase separation effectively or there could be chemical instabilities, because the desired product may be unstable, because of some microbial activity or metabolic. That means some metabolites are present which may be degrading your product composition or pH condition during extraction, that may affect the overall efficiency rheological property, the viscosity because the fermentation broths are highly viscous and when you are using a solvent and trying to extract, it is going to be big problem because viscosity will definitely affect the mass transfer as well as the extraction efficiency.

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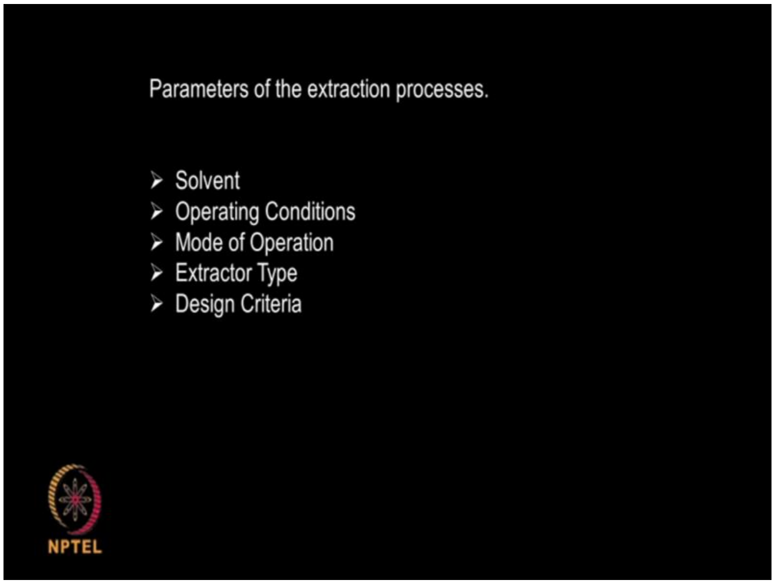

Parameters of the extraction processes.

- Solvent
- Operating Conditions
- Mode of Operation
- Extractor Type
- Design Criteria

So what are the parameters that affect extraction? Solvent, what type of solvent, I use operating conditions, What are the operating conditions? What should be the pH? What should be the temperature and so on.. Mode of operation, am I going to use batch mode, am I going to use multiple continuous mode and so on.. What are the extracted time, I am going to show you the pictures of different types of extractor and you will be surprised. A large number of extractors are available.

Then design criteria, what should be the size of the extractor, should it have mechanical agitation, non mechanical agitation, should it be a tower type and so on.. Those are all design criteria, so large type of design parameters that needs to be considered when you have to design an extractor and select an extractor okay.

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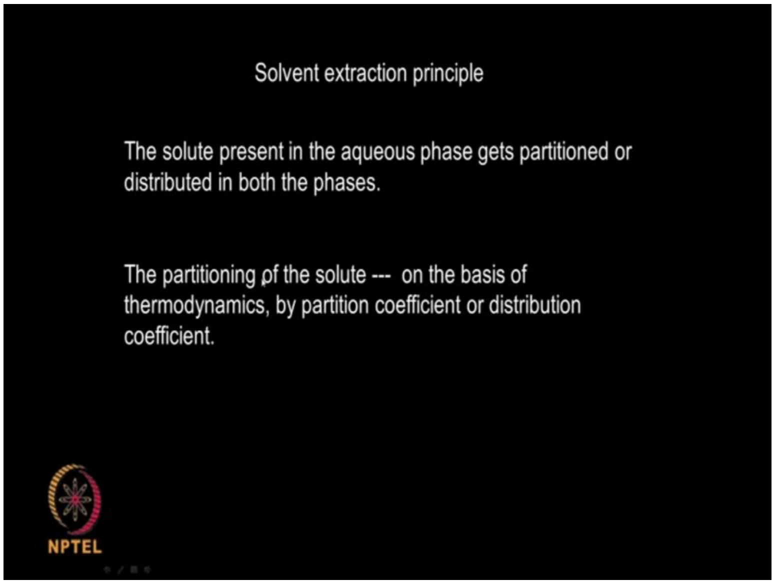

Solvent extraction principle

The solute present in the aqueous phase gets partitioned or distributed in both the phases.

The partitioning of the solute --- on the basis of thermodynamics, by partition coefficient or distribution coefficient.

So what is the principle which the extraction takes place. The solute present in one phase gets partitioned or distributed into another phase. This partitioning of the solute is based on thermo dynamic, based on partition coefficient or distribution coefficient. So we consider, we call it the partition coefficient. Generally partition coefficient we assume to be constant at a given temperature so the partition coefficient should be favorable towards the solvent, the solute so that can move into the solvent phase.

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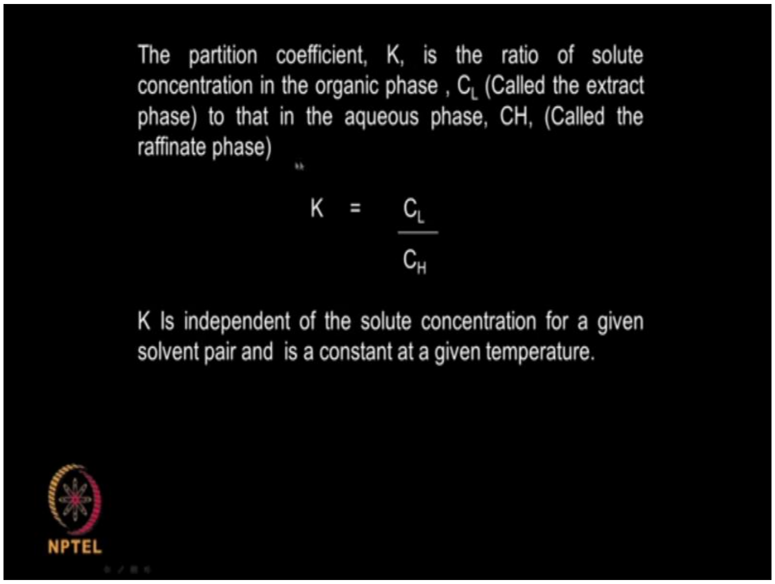

The partition coefficient, K, is the ratio of solute concentration in the organic phase , C_L (Called the extract phase) to that in the aqueous phase, CH, (Called the raffinate phase)

$$K = \frac{C_L}{C_H}$$

K Is independent of the solute concentration for a given solvent pair and is a constant at a given temperature.

So we define K the partition coefficient, that is the ratio of the solute in the solvent phase, that is organic phase or it is called extract phase / the concentration in the aqueous phase where or it is called heavy phase or raffinate phase and so on. So we can give different names for that. So this is like, this is a solvent phase, this is a extract phase and this is a heavy phase or aqueous phase or a raffinate phase. So this concentration is defined as K and generally K should be very large. Larger the K, better is the separation efficiency. I do not require too many extraction operations okay.

If smaller the K, then I need to resort too many extraction steps okay. So I need to select the solvent, so that the K value is pretty high for that solute. So for that particular solute K value should be high otherwise I need to change the solvent. It is constant at the given temperature so you can assume that it does not vary much between one stage to another as long as the stages are operated at the same temperature.

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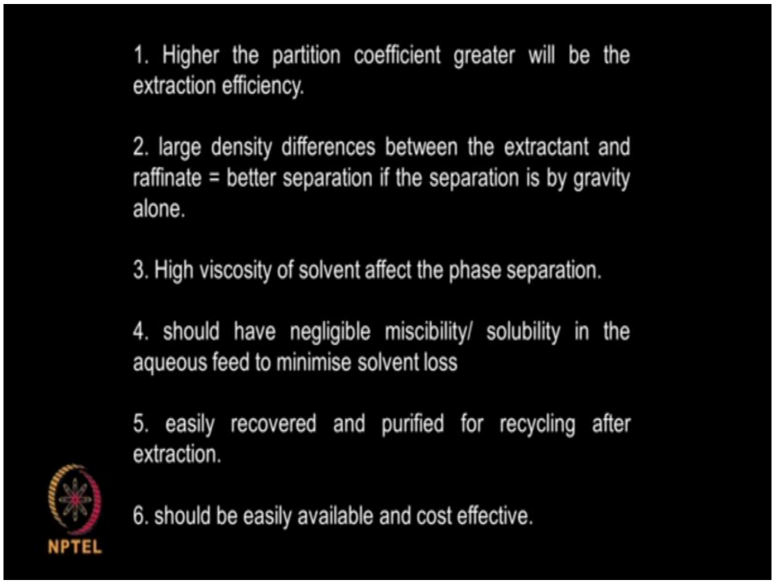

1. Higher the partition coefficient greater will be the extraction efficiency.

2. large density differences between the extractant and raffinate = better separation if the separation is by gravity alone.

3. High viscosity of solvent affect the phase separation.

4. should have negligible miscibility/ solubility in the aqueous feed to minimise solvent loss

5. easily recovered and purified for recycling after extraction.

6. should be easily available and cost effective.

So higher the partition coefficient, greater will be the extraction efficiency. Okay so obviously when I have higher partition coefficient, greater will be extraction efficiency. It will not require too many stages for separation. Large density difference better is the extractant and the raffinate separation right. The densities are very high, the phase separation is very fast and very effective. So if the densities or the differences are very small, phase separation is not very efficient.

Then I need to wait for a very long time and I will not be able to really see the phase separation. Okay, so the density plays a very important role not in the first part of the extraction but in the settling part of it high viscosity affects the phase separation, the solvent viscosity is very high. It is not going to immediately suffer separate. They should have negligible miscibility that means the solvent and the heavy or the raffinate should not be miscible.

If it is going to be miscible you are going to lose solvents okay. The solvent should be easily recovered and purified because I cannot throw the solvent after the extraction. I will remove the solvent and get the solute then that solvent should be recyclable. That means I should take it back and put it into my extraction process. It should be easily available, it should be cost effective. So these are very important. Cost ultimately plays a very important role.

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7. low interfacial tension between the phases facilitates the dispersion of phases and improves mass transfer. But - phase separation is difficult and time consuming thereby decreasing the throughput.

8. phyisoc-chemical properties such as boiling point, density, interfacial tension, viscosity, corrosiveness, flammability, stability, compatibility with product, availability should be satisfactory.

Low inter-facial tension between the phases, then dispersion of phases is good, mass transfer is good but then inter-facial tension is low, then the face separation becomes difficult, so it takes much longer time for the faces to separate. So if the inter-facial tension is low, you get good separation. You get good mass transfer but later on the settling of the heavy with the light becomes a time consuming process okay and another physioc-chemical properties such as boiling point, density.

Inter-facial tension, viscosity, how corrosive it is, is it flammable, is it toxic, is it safer to handle, all those factors are also considered when you decide on a solvent. Should I take a chloroform, should I take a acetone, should I take a methanol, should I toluene, should I take a hexane, so you decide based on all these parameters okay and the type of solute which you are trying to use.

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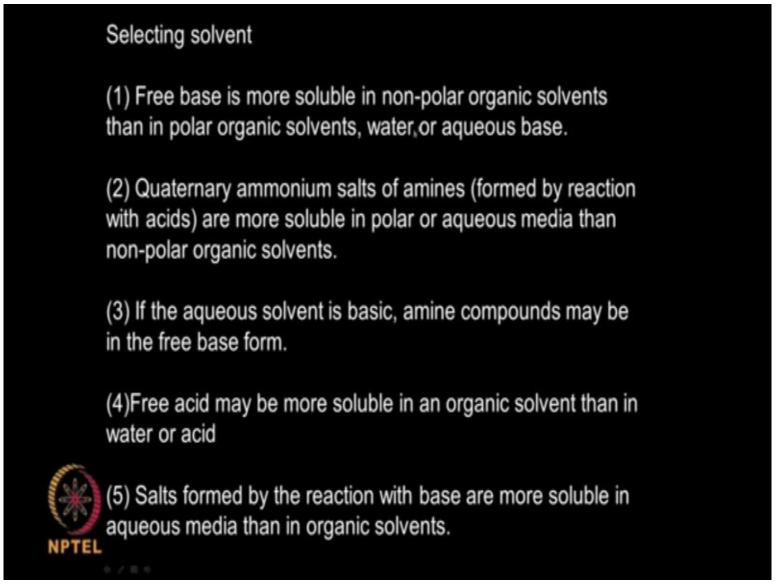

Selecting solvent

(1) Free base is more soluble in non-polar organic solvents than in polar organic solvents, water,or aqueous base.

(2) Quaternary ammonium salts of amines (formed by reaction with acids) are more soluble in polar or aqueous media than non-polar organic solvents.

(3) If the aqueous solvent is basic, amine compounds may be in the free base form.

(4)Free acid may be more soluble in an organic solvent than in water or acid

(5) Salts formed by the reaction with base are more soluble in aqueous media than in organic solvents.

Selecting solvents we have many criteria like for example free base is more soluble in non polar organic solvents okay free base than in polar organic solvents okay such as water or aqueous base. If you take quaternary ammonium salts or amines formed by reactions with acids, they are more soluble in polar or aqueous media that the non-polar, so I would select a polar solvent, if I am trying to extract quaternary ammonium salts.

If I am trying to extract free bases, then I would rather go for a non-polar organic solvents, if the aqueous solvent is basic, amine compounds may be in the free base form. Okay if free as it may be more soluble in organic solvent than in water or acid okay free acid. Salts formed by the reaction with base are more soluble in aqueous media than in organic solvents. So if I have salts that are formed with the react thing with some base okay, then I would rather use aqueous media than organic solvents.

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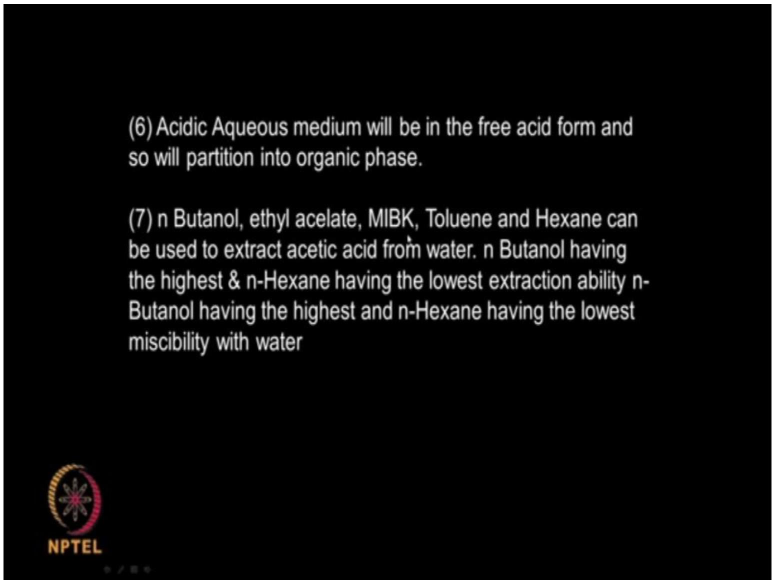

(6) Acidic Aqueous medium will be in the free acid form and so will partition into organic phase.

(7) n Butanol, ethyl acelate, MIBK, Toluene and Hexane can be used to extract acetic acid from water. n Butanol having the highest & n-Hexane having the lowest extraction ability n-Butanol having the highest and n-Hexane having the lowest miscibility with water

I said acidic aqueous medium will be in the free acid form and so will partition into organic phases n Butanol, ethyl acetate, mibk, toluene and hexane can be used to extract acetic acid from water. So n Butanol will have the highest and hexane will have the lowest extraction ability okay and n Butanol having the highest and n-hexane with the lowest miscibility with water. So if I have acidic acid with water, so I would rather select n Butanol because it will have the lowest miscibility with water okay

And it will have the highest extraction efficiency. So there are certain conditions whether it is a free base, whether it is acidic, whether it is a salt, whether it is polar compound, whether it is a non polar compound, so we can select solvents based on these conditions as well so that separation is efficient visibility between the raffinate and the solvent is also minimum.

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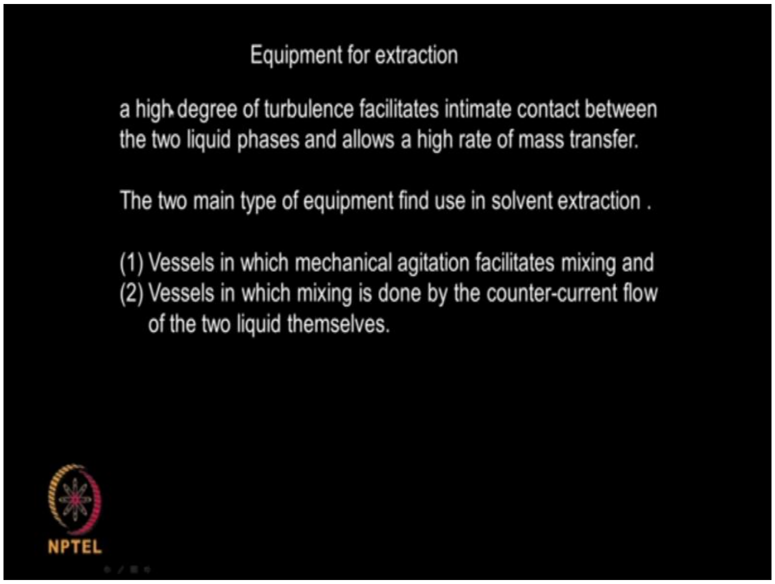

Equipment for extraction

a high degree of turbulence facilitates intimate contact between the two liquid phases and allows a high rate of mass transfer.

The two main type of equipment find use in solvent extraction .

(1) Vessels in which mechanical agitation facilitates mixing and
(2) Vessels in which mixing is done by the counter-current flow of the two liquid themselves.

So what are the equipments that are used. Two types of equipments that are generally used is mechanical agitation because that will facilitate mixing and those counter-current flow of two liquids and the main goal is to bring in an intimate contact between the 2 liquid and allow a high rate of mass transfer. So here we want to bring a very good contact we want to increase the surface area continuously between these 2 liquids number one. Number 2 we want to enhance the mass transfer operation so this is how it is done.

So if you use a mechanical agitation you get a very good agitation surface renewal you are using more energy but then in counter-current systems we have better mixing also using tower type of extracting equipments and so on.

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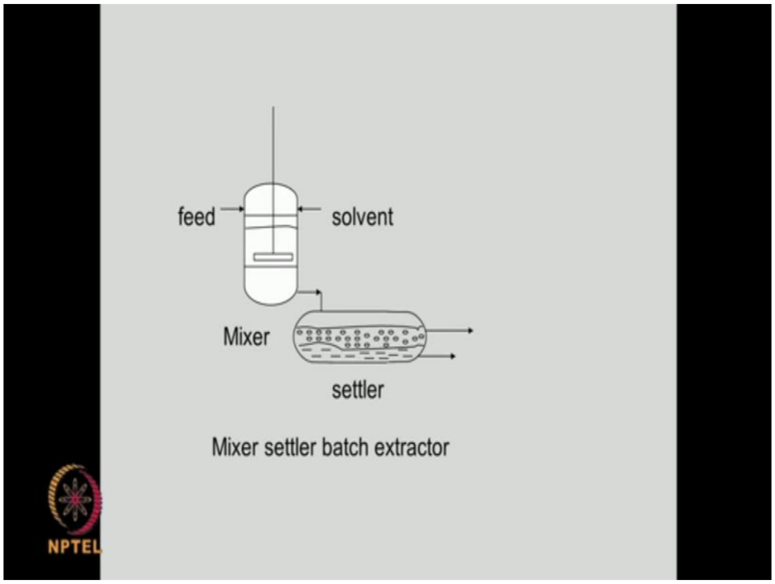

Mixer settler batch extractor

So we look at some of those designs here okay this is the simplest of the lot it is called the mixer settler batch extractor. So what you do is you take your feed here and then you take your solvent you agitate for intimate mixing and then you drop it into a settler. So they form 2 layers you give sufficient time so that they form 2 layers and then you remove your solvents and then you remove your raffinate. If the solvent is heavy, it will be collected at the bottom, the raffinate will be collected at the top if vice versa.

It will be so if the solvent is light. So this is called one stage mixer settler operation. So I can have many stages like this okay or I can do the same thing, I can draw both of them down and then I put I can put in my raffinate, I can add some solvent and I can achieve some separation. So this operation can be done many times using the same setup. So when every time I do I will call it one stage operations. So mixer settler is quite simple, needs agitator and settling tank here. Actually it occupies lot of floor space actually, remember that okay.

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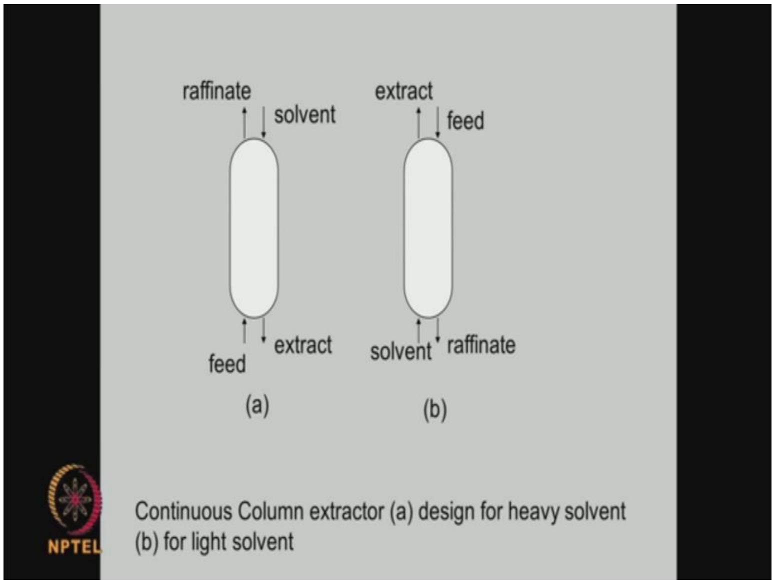

Continuous Column extractor (a) design for heavy solvent (b) for light solvent

Another type is the column extractor these occupy less space, so tall columns are there okay, you can see the tall columns here, you have a solvent coming in here, in the other case solvent coming from the bottom okay. If the solvent is light, generally then the heavy relatively solvent will come from the bottom. If the feed is heavier than the solvent then the feed comes from the bottom actually okay. So if the solvent is very light it can rise up if the solvent is very heavy it can come down. So this is called a continuous column extractor.

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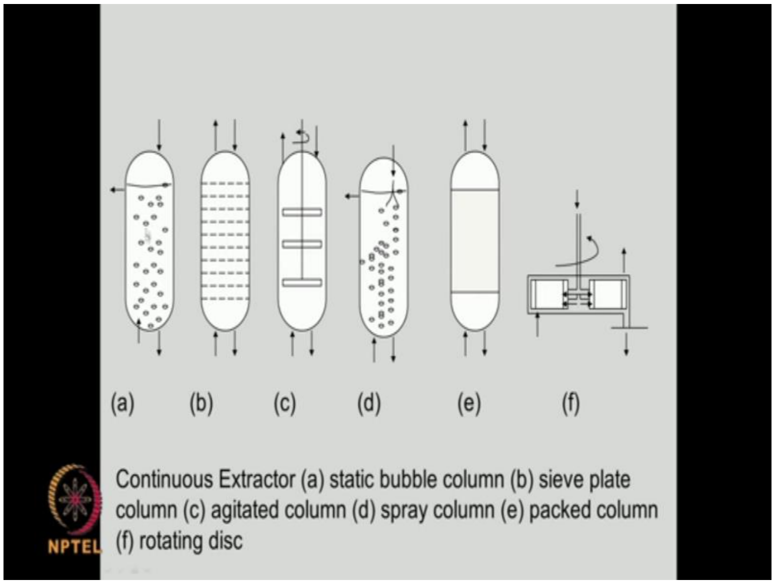

Continuous Extractor (a) static bubble column (b) sieve plate column (c) agitated column (d) spray column (e) packed column (f) rotating disc

As you can see the floor space, it occupies less. So you have a large number of designs available. This is a static double column, you can see there is no agitation here. So bubble column, so the solvent is entering in the form of bubbles and we have the heavy is coming down or vice versa is also possible. Then we have the sieve plate, you have the lot of plates with holes, so that there is agitation because of small mixing that is taking place.

So we have in a counter-current fashion, you have solvent moving in one direction and the heavy is moving in another direction or the feed moving in another direction. Then the third type is agitated column. So in these 2 it is not agitated whereas you can also have a very long shear shaft okay and slowly agitate, so that you bring in certain intimate contact and enhance the mass transfer coefficient you can have many blades here along across or along the shaft okay.

The fourth design is spray type, so you are spraying one of the liquids from the top and the other liquid is totally filled up so you are bringing in lot of new mass transfer area. The next design is called packed column, so you have packing here and these solvent is flowing in one direction and there the feed is flowing in another direction. The fourth another type is called the rotating disk okay so you have one phase coming here.

There is large disk inside it is rotating and the solvent is introduced inside the shaft because of the centrifugal force, it hits and gets mixed up with the other phase. so the mass transfer rates are very very high because one of the phases is thrown outside because of the centrifugal force that gives you a very large velocity and it gives you a very large mass transfer coefficient also. So with this type of rotating disk we can achieve very large mass transfer coefficient with very small setup.

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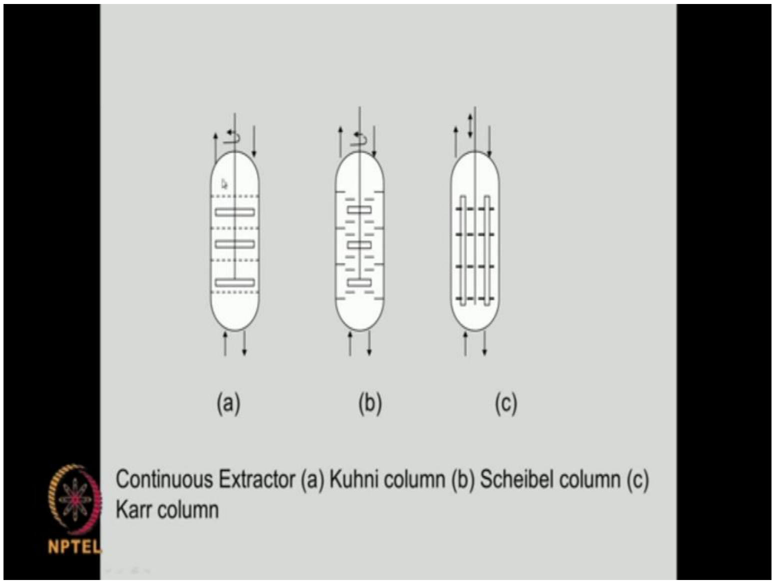

Continuous Extractor (a) Kuhni column (b) Scheibel column (c) Karr column

Again more designs, this is a continuous extractor, this is called a kuhni column. Okay so you have sieve plates as well as agitation here, then you can you have scheibel column, you have a small compartments like and then we have agitator so each compartment is like a stage. And then the next one is karr column, here the agitator moves up and down like this. Where it rotates so here it moves up and down, so all these designs are meant to bring in some intimate contact.

So as you can see we shot 2 types of design. One is mechanical agitation to improve the mass transfer and surface renewal and the other one is the non mechanical agitation where there are no mechanical agitation but the contact happens because of the sieve plates or because of the compartments of because of the formation of bubbles and so on actually.

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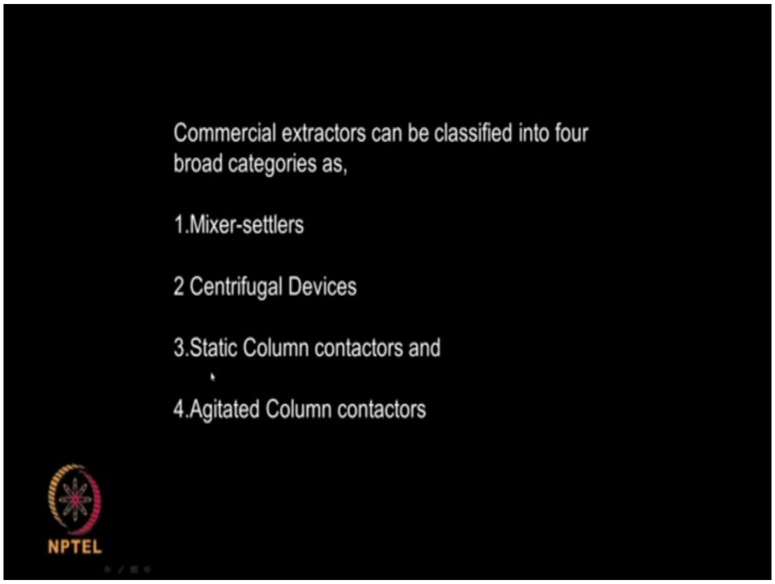

Commercial extractors can be classified into four broad categories as,

1.Mixer-settlers

2 Centrifugal Devices

3.Static Column contactors and

4.Agitated Column contactors

So 2 designs and you also have centrifugal devices, I showed you one picture of that. Then of course in the column we have static column, where you are not agitating anything but you have and then on the contrary you can have a column as well as with the agitation. So four types totally in total each on has got their advantages disadvantages and you select based on your requirements okay.

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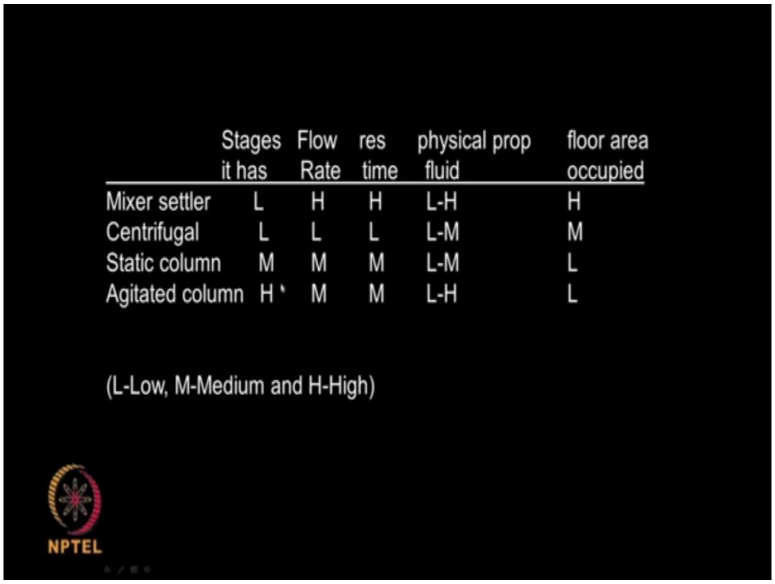

	Stages it has	Flow Rate	res time	physical prop fluid	floor area occupied
Mixer settler	L	H	H	L-H	H
Centrifugal	L	L	L	L-M	M
Static column	M	M	M	L-M	L
Agitated column	H	M	M	L-H	L

(L-Low, M-Medium and H-High)

So for example stages it has we can have large number of stages in agitated column, we can have medium number of stages in static and mixer settler very low. Flow rate we can achieve very high flow rate in mixer settler low flow rate in centrifugal resistance time generally is very very high because we are to give sufficient time for it to settle whereas in agitated columns, we can have medium residence time and centrifugal residence time is very very low.

Floor space occupied mixer settler occupies very large floor space whereas agitated columns occupies very low floor space. So you see some of them have advantages in stages on them, some of them got disadvantages in floor occupied, some of them have advantages in residence time, some of them have advantages in throughput. So depending upon the physioc-chemical properties of the solvent, you use the physioc-chemical properties of the fermentation broth and what you want to extract you select whatever you want to do actually.

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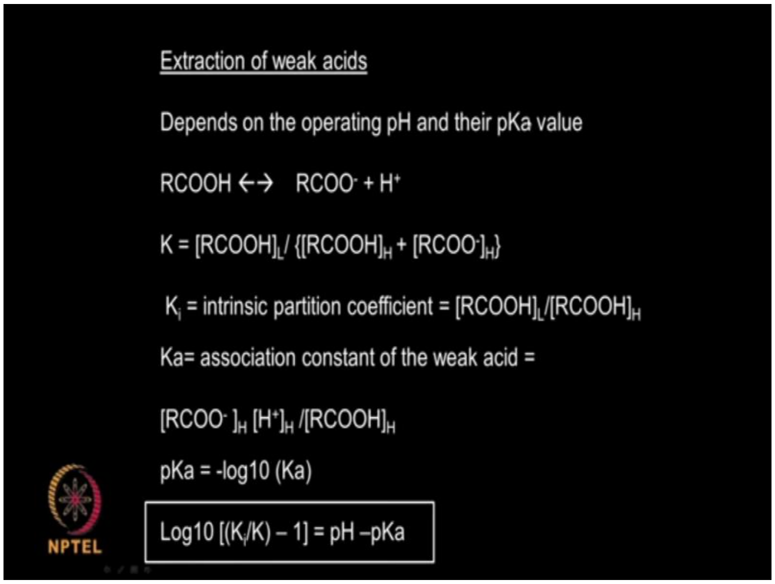

Extraction of weak acids

Depends on the operating pH and their pKa value

$RCOOH \leftrightarrow RCOO^- + H^+$

$K = [RCOOH]_L / \{[RCOOH]_H + [RCOO^-]_H\}$

K_i = intrinsic partition coefficient = $[RCOOH]_L/[RCOOH]_H$

Ka= association constant of the weak acid =

$[RCOO^-]_H [H^+]_H /[RCOOH]_H$

pKa = -log10 (Ka)

$\boxed{\text{Log10 } [(K_i/K) - 1] = \text{pH} - \text{pKa}}$

Okay so extraction of weak acids it depends on the operating pH and the pKa value so you all know pKa pKa what is pKa pKa is the pH at which this dissociates right okay so you have acid RCOOH it can dissociate to form RCOO- + H -. Okay now if you look at the partition coefficient K, so we have RCOOH liquid by RCOOH and then RCOO- H. So you because we have RCOOH in the liquid form and when it goes to the heavy it will have RCOOH and RCOO-H.

The intrinsic partition coefficient will be RCOOH in the solvent phase / the RCOOH in the heavy phase now if you look at the partition coefficient in the reality you have 2 terms here because the RCOOH can go into RCOOH - as well in the aqueous medium because it dissociates okay. So we have 2 terms here so we have 2 types of partition coefficient right K that the Ki is the partition coefficient and K the real partition coefficient and here we also have ka that is the association constant that for the weak acid

Okay that is ratio of RCOO- * H - / RCOOH in the H in the heavy phase and pKa is nothing but logarithm to the base 10 of K that is the association constant. So we can get a relationship between K Ki and Ka. So log10 Ki/K that is intrinsic partition coefficient by the actual partition coefficient = pH-pKa so depending upon the pH these the Ki can change okay depending upon the pH the ki can change because your dissociation can change that is the extraction of weak acid.

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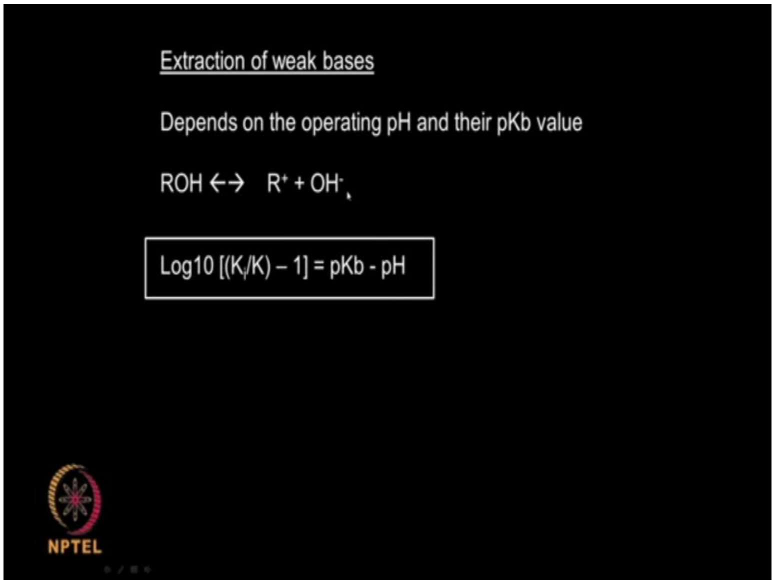

Extraction of weak bases

Depends on the operating pH and their pKb value

ROH ←→ $R^+ + OH^-$

$$\boxed{\mathrm{Log10}\,[(K_i/K) - 1] = pKb - pH}$$

So similarly you can have weak bases also here we have ROH going to r - and oh and this depends upon the pKb so analogous to the ex weak acids we can have log 10 (Ki/K)-1 is equal to pKb – pH. So in the previous case we have log 10 (Ki/K) - 1 = pH-pKa here we have pKb-pH okay so these are the differences okay so here pKb - pH then here pH–pKa.

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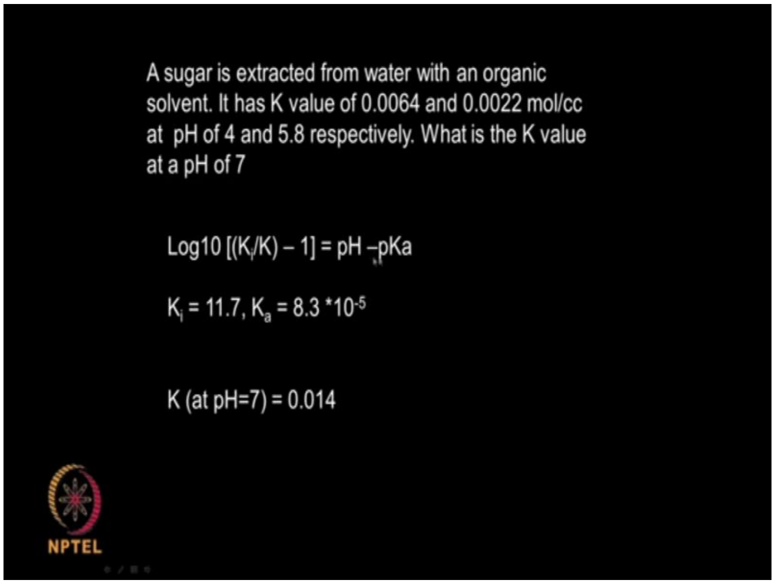

A sugar is extracted from water with an organic solvent. It has K value of 0.0064 and 0.0022 mol/cc at pH of 4 and 5.8 respectively. What is the K value at a pH of 7

$$\mathrm{Log10}\,[(K_i/K) - 1] = pH - pKa$$

$K_i = 11.7$, $K_a = 8.3 * 10^{-5}$

K (at pH=7) = 0.014

Okay now let us look at a simple problem a sugar is extracted from water with an organic solvent it has a K value of 0.0 0064 and 0.0022 mol per cc at these 2 pH what is the K value at a pH of 7 okay so what do you have to do? We have to take log 10 Ki/K- 1 = pH-pKa so at pH=4 okay I know the K value at pH=5.8 I know the K value so I need to know what is the K at pH=7 so you using these two data I can calculate both the Ka and I can calculate Ki okay and then I use them and for a pH of 7 I will find out what will be the K value okay you understand.

So from this equation, you have this equation I know at a pH of 4, the K value is something and at a pH of 5 point 5.8, the K value is something, so I get 2 equations I solve them I calculate the pKa or ka then I calculate Ki so what is Ki. Ki is the intrinsic partition coefficient that is if there is no dissociation, you know the concentration in the liquid phase / concentration in the heavy phase right but because the base dissociates in the in the aqueous media you are having extra species which is RCOO- that is why you get this K.

Whereas the intrinsic partition coefficient assumes that is no few, there is no dissociation, so we have the concentration of the solute in the liquid concentration of the solute in the heavy phase okay. So we can do that and thereby we can get the answer for K so you can see the K varies as a function of pH ka may be the constant what is K once more Ki is the intrinsic partition coefficient so it does not change because it does not assume if the there is dissociation but K assumes dissociation

And you have the extra term here that is why K changes as a function of pH whereas ki does not change as a function of pH okay.

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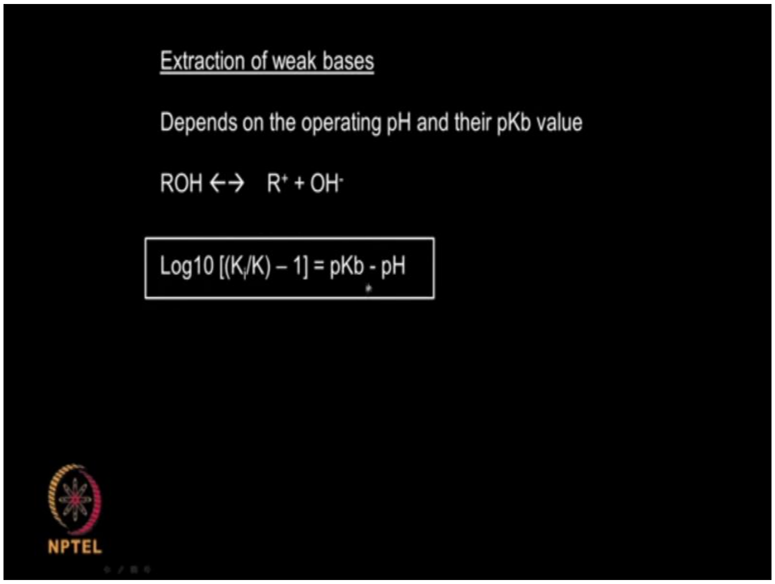

Extraction of weak bases

Depends on the operating pH and their pKb value

$ROH \leftrightarrow R^+ + OH^-$

$$\boxed{\text{Log10}\,[(K_i/K) - 1] = pKb - pH}$$

So similar thing if you have problems to be basis we can do the same thing actually right so of course again here also we will have K not changing with pH whereas K will change with pH because as pH changes the dissociation of the weak bases also follows this particular relationship. So that is what this problem is all about actually.

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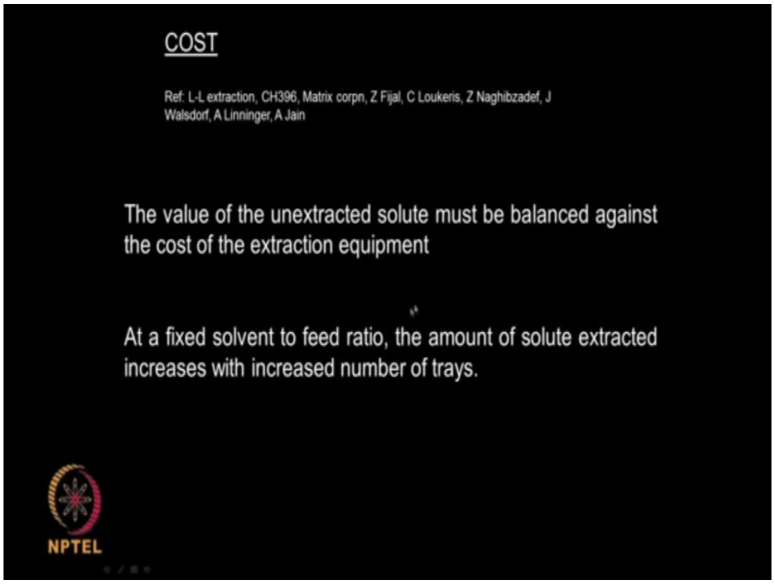

COST

Ref: L-L extraction, CH396, Matrix corpn, Z Fijal, C Loukeris, Z Naghibzadef, J Walsdorf, A Linninger, A Jain

The value of the unextracted solute must be balanced against the cost of the extraction equipment

At a fixed solvent to feed ratio, the amount of solute extracted increases with increased number of trays.

Now cost, cost play a very important role ultimately. Because I keep on talking about cost, cost, cost. So at a fixed solvent to feed ratio the amount of solute extracted increase with the increase of tray, if I have more tray or if I have more stages then obviously cost will go up. So I need to balance how much I want to extract was cost of an equipment so if I am going to extract 90 % cost of equipment will be something. But if I want to go to 99 % obviously cost will go up because I may have to go for more stages.

So is it worth extracting all the 99 % so you need to consider that so if it is a bulk chemical may be, it might not be very useful but if it is a very high value chemical it very useful so you need to balance that right.

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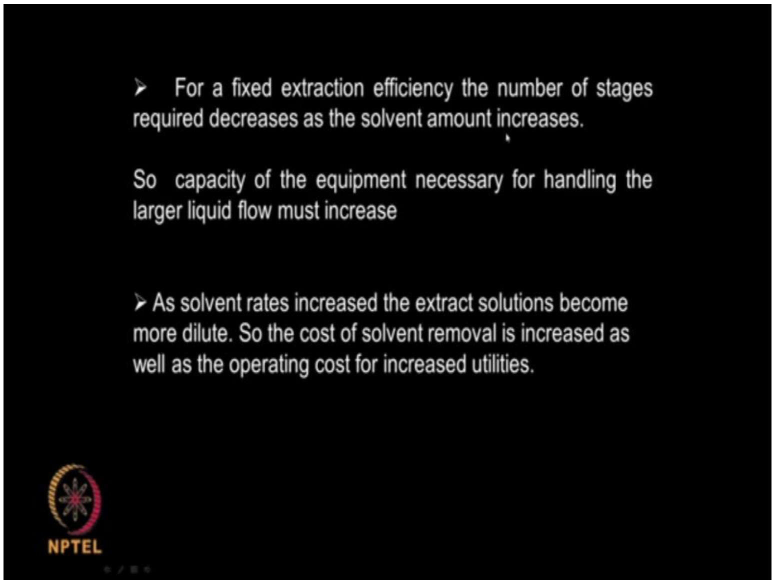

- For a fixed extraction efficiency the number of stages required decreases as the solvent amount increases.

So capacity of the equipment necessary for handling the larger liquid flow must increase

- As solvent rates increased the extract solutions become more dilute. So the cost of solvent removal is increased as well as the operating cost for increased utilities.

For a fixed extraction efficiency the number of stages required decrease as the solvent amount increases so if I use more solvent for the same efficiency I will require less number of stages but then I am using more solvent that means my equipment size has to go up because I am using more solvent but then if I am using more solvent I need to get the solvent back okay. That means I need to have a distillation column to remove the solvent so my operating cost goes up okay.

So if I am using more solvent, my efficiency increases, my stages decreases, so I am saving on cost but my size of equipment inc increases because I am going to use more solvent, there cost is increasing, my running cost increases because I have to recover the solvent using a distillation column may be bigger distillation column. So you see in some, the number of stages decreases but the size of stages increases, my operating cost increases because I need to remove more solvent so there is lot of + and – .

You need to balance depending upon cost we need to balance depending upon the price of the product is it worth it and so on actually.

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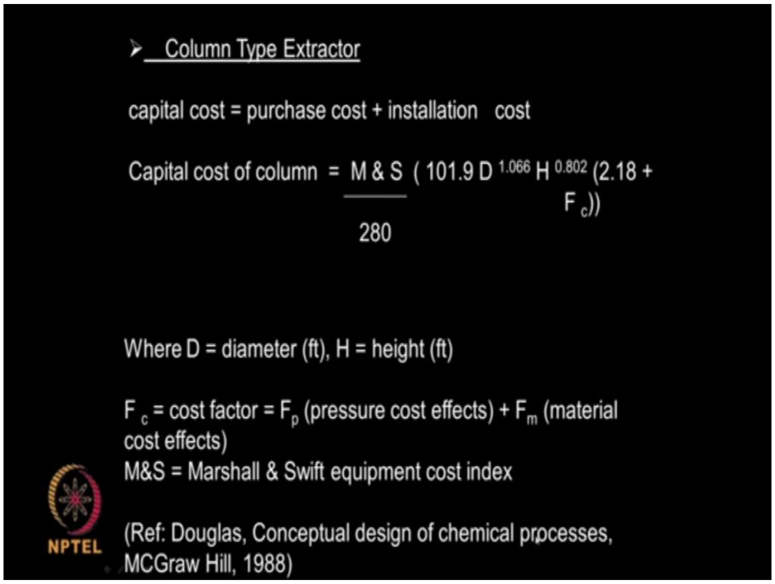

- Column Type Extractor

capital cost = purchase cost + installation cost

Capital cost of column = $\frac{M \& S}{280}\left(101.9\, D^{1.066} H^{0.802} (2.18 + F_c)\right)$

Where D = diameter (ft), H = height (ft)

F_c = cost factor = F_p (pressure cost effects) + F_m (material cost effects)

M&S = Marshall & Swift equipment cost index

(Ref: Douglas, Conceptual design of chemical processes, MCGraw Hill, 1988)

So there are some relationship available ball park fill relationship and you can look at this book conceptual design of chemical processes McGraw hill. So capital cost of a column they have said M and S that is Marshal and Swift equipment cost index diameter of the column, height of the column and some cost factor.

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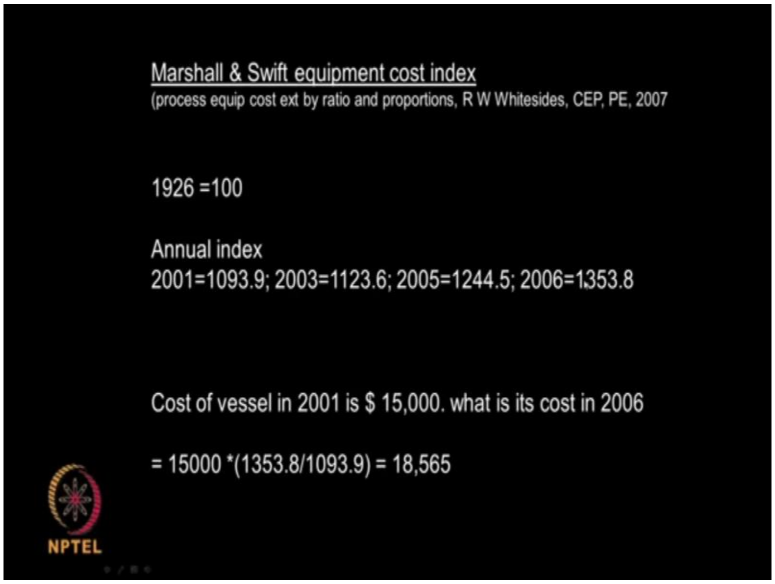

Marshall & Swift equipment cost index

(process equip cost ext by ratio and proportions, R W Whitesides, CEP, PE, 2007

1926 =100

Annual index

2001=1093.9; 2003=1123.6; 2005=1244.5; 2006=1353.8

Cost of vessel in 2001 is \$ 15,000. what is its cost in 2006

= 15000 *(1353.8/1093.9) = 18,565

So they will take a year for example 1926 as hundred, then the year 2001 becomes 1093, year 2006 becomes 1353, so depending upon the year we put in some number and then f is the cost factor this cost factor depends upon the pressure cost effect material cost effect. Suppose if I am using very exotic material cost goes up if I am using mild steel it is cheaper if I am using atmospheric pressure it is cheaper I am going to 10 bar pressure then cost goes up so this cost factor takes care of these 2 terms

And m and s starts from the year 1926 is 100 and then keeps multiplying as you can see for the year 2006 is 1353. So cost of vessel in 2001 is 15000 what is the cost in 2006 so I can put it those numbers 15000 and then I will put in the m and s factor and so on I will get it is about 18565 dollars

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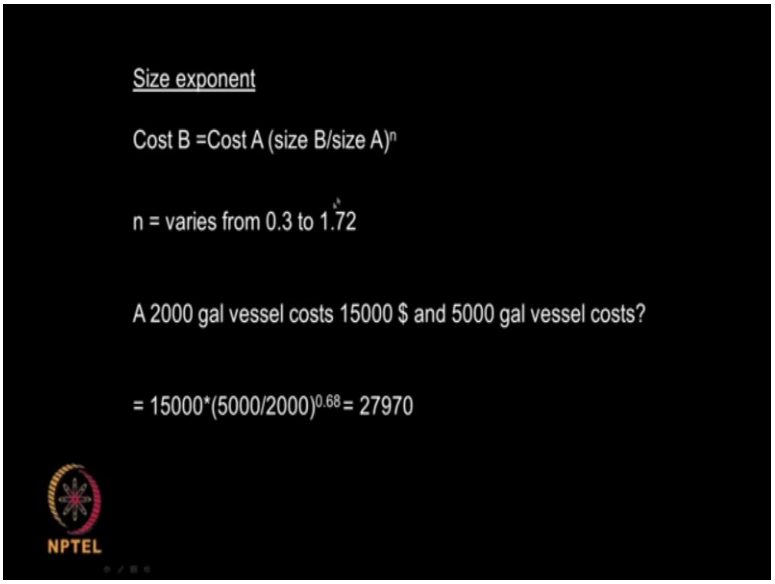

Size exponent

Cost B =Cost A (size B/size A)^n

n = varies from 0.3 to 1.72

A 2000 gal vessel costs 15000 $ and 5000 gal vessel costs?

= 15000*(5000/2000)$^{0.68}$ = 27970

Size again if you remember I talked about the 0.6 exponent type of 0.6 where cost of b = cost of a size of b / size of a raised to the power n. So these numbers can change between 0.3 to 1.72. So if I know the cost of 2000 gal vessel is 15000 dollars, what is the cost of a 5000 gal vessel, I can put in and I put in the proper n here I have taken as 0.88.

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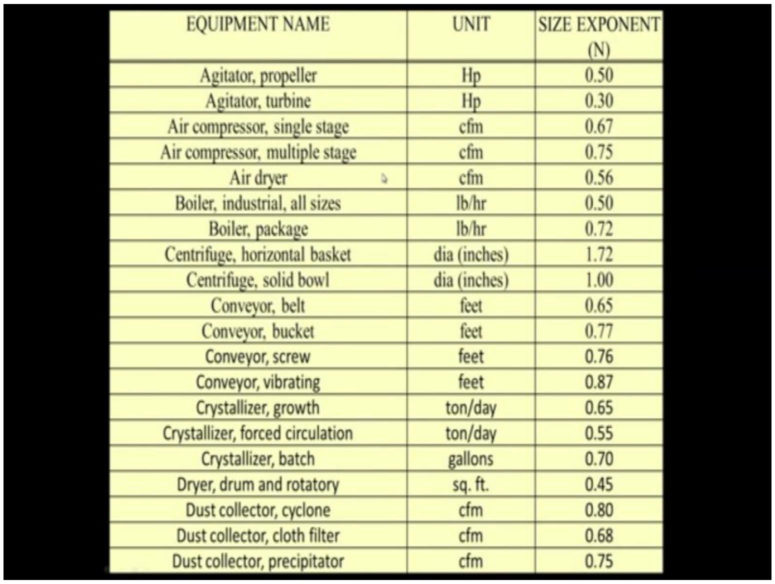

EQUIPMENT NAME	UNIT	SIZE EXPONENT (N)
Agitator, propeller	Hp	0.50
Agitator, turbine	Hp	0.30
Air compressor, single stage	cfm	0.67
Air compressor, multiple stage	cfm	0.75
Air dryer	cfm	0.56
Boiler, industrial, all sizes	lb/hr	0.50
Boiler, package	lb/hr	0.72
Centrifuge, horizontal basket	dia (inches)	1.72
Centrifuge, solid bowl	dia (inches)	1.00
Conveyor, belt	feet	0.65
Conveyor, bucket	feet	0.77
Conveyor, screw	feet	0.76
Conveyor, vibrating	feet	0.87
Crystallizer, growth	ton/day	0.65
Crystallizer, forced circulation	ton/day	0.55
Crystallizer, batch	gallons	0.70
Dryer, drum and rotatory	sq. ft.	0.45
Dust collector, cyclone	cfm	0.80
Dust collector, cloth filter	cfm	0.68
Dust collector, precipitator	cfm	0.75

There are data available for example for different equipment we can see the n value is given here for different equipments for agitators, for collectors, for conveyors, centrifuges.

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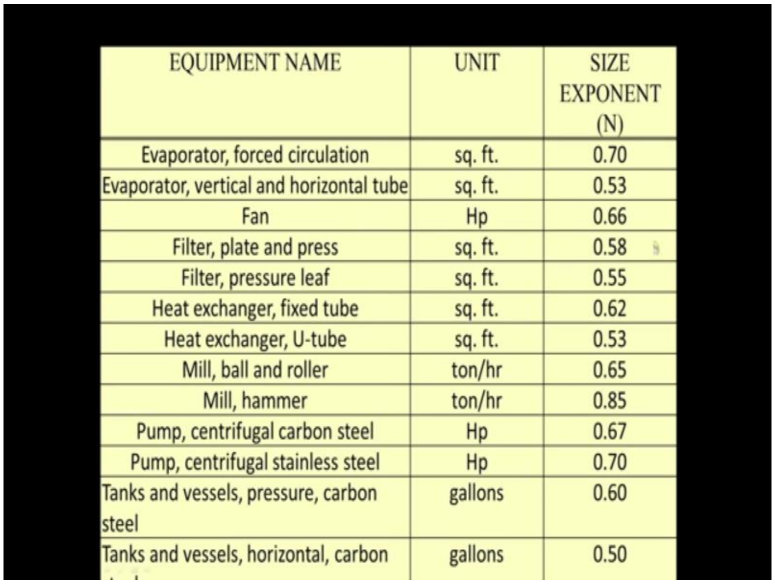

EQUIPMENT NAME	UNIT	SIZE EXPONENT (N)
Evaporator, forced circulation	sq. ft.	0.70
Evaporator, vertical and horizontal tube	sq. ft.	0.53
Fan	Hp	0.66
Filter, plate and press	sq. ft.	0.58
Filter, pressure leaf	sq. ft.	0.55
Heat exchanger, fixed tube	sq. ft.	0.62
Heat exchanger, U-tube	sq. ft.	0.53
Mill, ball and roller	ton/hr	0.65
Mill, hammer	ton/hr	0.85
Pump, centrifugal carbon steel	Hp	0.67
Pump, centrifugal stainless steel	Hp	0.70
Tanks and vessels, pressure, carbon steel	gallons	0.60
Tanks and vessels, horizontal, carbon	gallons	0.50

Evaporators, tanks, heat exchangers, pumps you can see know for different equipment the n is there so we can use this n so I know the cost of the equipment I can find of cost of a new equipment using this rule actually.

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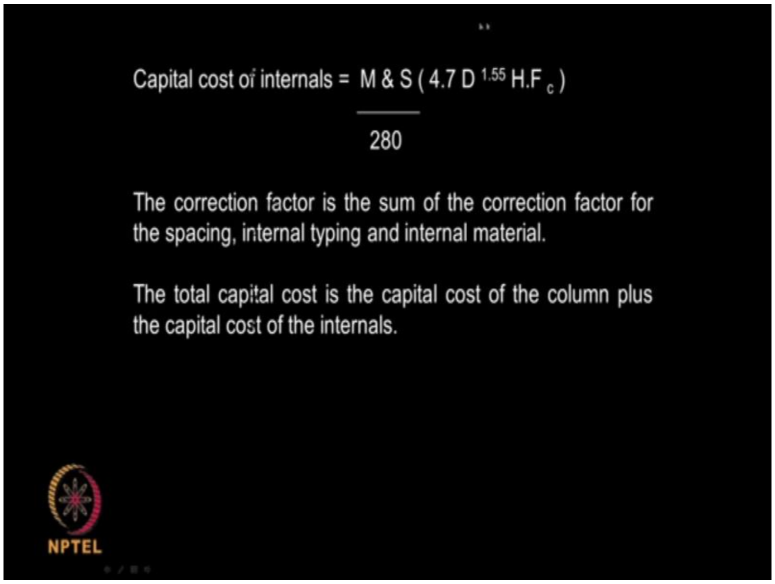

$$\text{Capital cost of internals} = \frac{\text{M \& S} \left(4.7\, D^{1.55}\, H . F_c\right)}{280}$$

The correction factor is the sum of the correction factor for the spacing, internal typing and internal material.

The total capital cost is the capital cost of the column plus the capital cost of the internals.

So but then you if you have a column you are also going to have internals right, so you need to have one more term for the internals. Internals means packing different types of packing material may be there. So you need to add that cost also into the cost.

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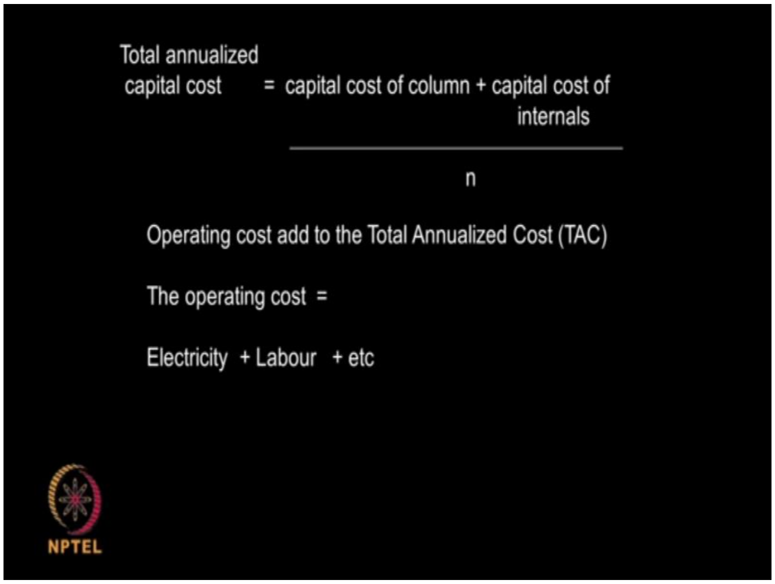

$$\text{Total annualized capital cost} = \frac{\text{capital cost of column} + \text{capital cost of internals}}{n}$$

Operating cost add to the Total Annualized Cost (TAC)

The operating cost =

Electricity + Labour + etc

So the total capital cost will be capital cost of the column - capital cost of the internals okay so annualized capital cost will be / n. n is the age of the equipment so this gives you some idea about the of the depreciation.

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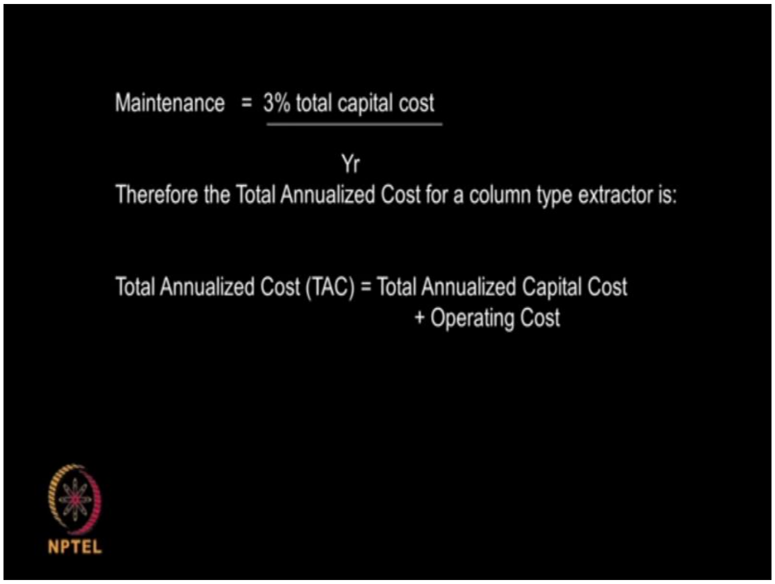

$$\text{Maintenance} = \frac{3\%\ \text{total capital cost}}{\text{Yr}}$$

Therefore the Total Annualized Cost for a column type extractor is:

Total Annualized Cost (TAC) = Total Annualized Capital Cost + Operating Cost

Now operating cost will be electricity labor all those things will come into operating cost right, okay so maintenance will be certain percentage of capital cost, so the total annualized cost is all these terms added up together.

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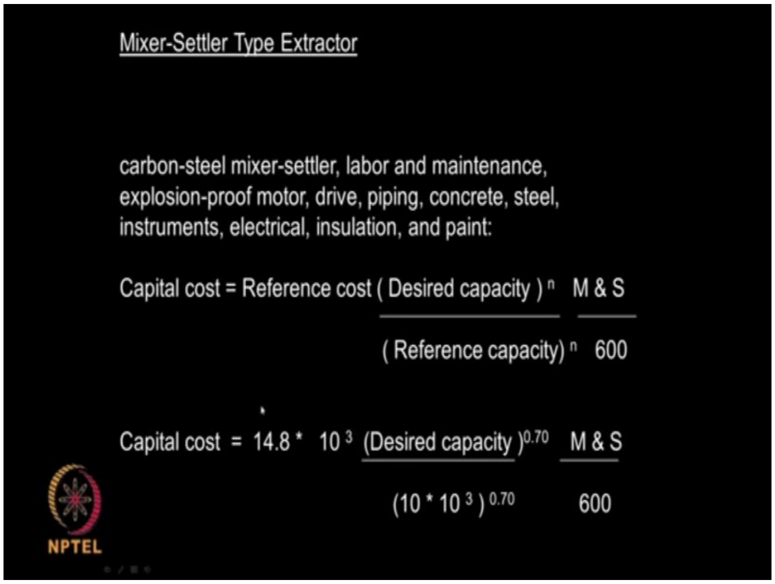

Mixer-Settler Type Extractor

carbon-steel mixer-settler, labor and maintenance, explosion-proof motor, drive, piping, concrete, steel, instruments, electrical, insulation, and paint:

$$\text{Capital cost} = \text{Reference cost}\,\frac{(\text{Desired capacity})^{n}}{(\text{Reference capacity})^{n}}\,\frac{M\,\&\,S}{600}$$

$$\text{Capital cost} = 14.8 * 10^{3}\,\frac{(\text{Desired capacity})^{0.70}}{(10 * 10^{3})^{0.70}}\,\frac{M\,\&\,S}{600}$$

Okay if take mixer-settler type of extractor, we have some relationship for capital cost. Okay so it is 14.8*10 power 3 whatever capacity you want you put in the M and S factor and then this is the reference capacity okay and you are raising it by 0.7 here the exponent is 0.7 okay that is for the mixer-settler type.

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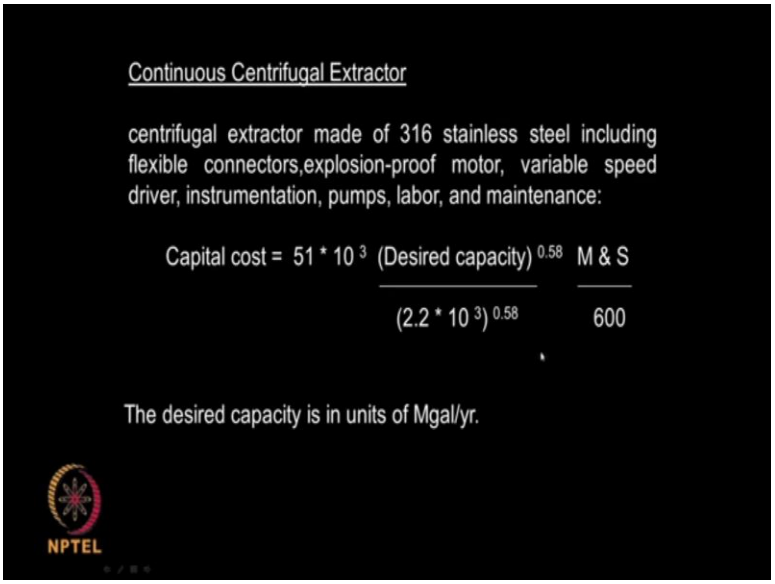

Continuous Centrifugal Extractor

centrifugal extractor made of 316 stainless steel including flexible connectors,explosion-proof motor, variable speed driver, instrumentation, pumps, labor, and maintenance:

$$\text{Capital cost} = 51 * 10^{3}\,\frac{(\text{Desired capacity})^{0.58}}{(2.2 * 10^{3})^{0.58}}\,\frac{M\,\&\,S}{600}$$

The desired capacity is in units of Mgal/yr.

Similarly for a continuous centrifugal extractor we have some formula here and here the exponent is 0.58 okay this is using a material of 316 stainless steel as a material okay. So you see that the different types of equipment we have different costs and depending upon the material of construction the cost will change. The all these cost will just give the idea when you are selecting equipment cost should play a very important role but if you want to know the exact cost you may have to go to the vendor and find out what is the exact cost.

But it gives you an idea about should I go for a centrifugal extractor or mixer-settler or a column extractor and so on actually okay.

Thank you very much!!