Reversed Micellar And Aqueous Two Phase Extraction
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Lecture - 20
Reversed Micellar And Aqueous Two Phase Extraction

For the past 5 classes we have been talking about Liquid- Liquid Extraction; where you use an organic solvent or you use water itself for extracting your desired product. The desired product could be a protein or it could be a small molecule metabolite or it could be an amino acid and so on. Liquid -Liquid Extraction is a staged process that means; you have several stages; you can perform the extraction in 1 single stage or you can allow it to mix separating many several stages.

We also looked at the co-current and the counter current approach as well as the cross current approach for a Liquid- Liquid Extraction. And, also we looked at design of number of stages based on certain extraction efficiency whether it is a cross current or whether it is a counter current operation or conversely a given the number of stages how to estimate the extraction efficiency?

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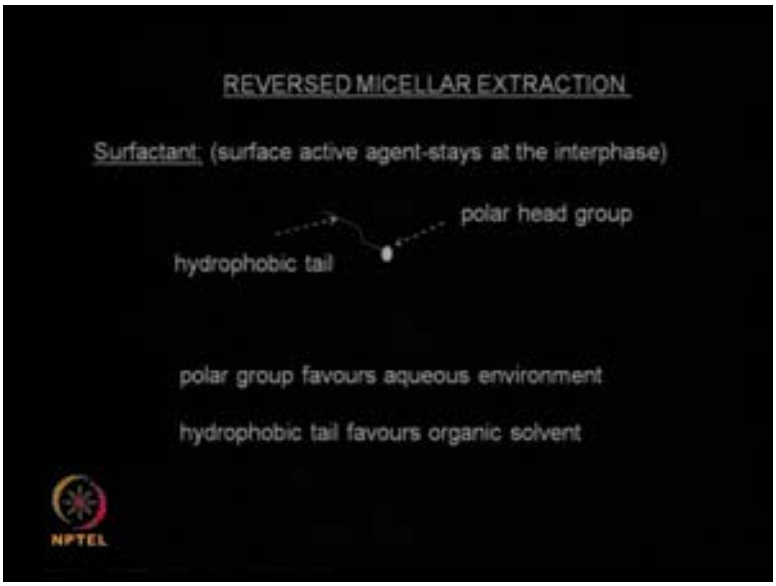

Then, in the previous class we looked at the revered micellar extraction which is very very important if you are extracting a protein or a peptide or any molecule which is very

solvent sensitive; that means they lose their activity in the presence of solvents. So, in such situations we use a surfactant or a surface active agent which will partition near the 2 different distant layers, that is the water layer as well as the solvent layer. The surfactant has an interesting property it is got a hydrophobic tail as well as a polar head group. So, it partitions the polar head group goes to the aqueous layer and the hydrophobic tail goes to the solvent layer.

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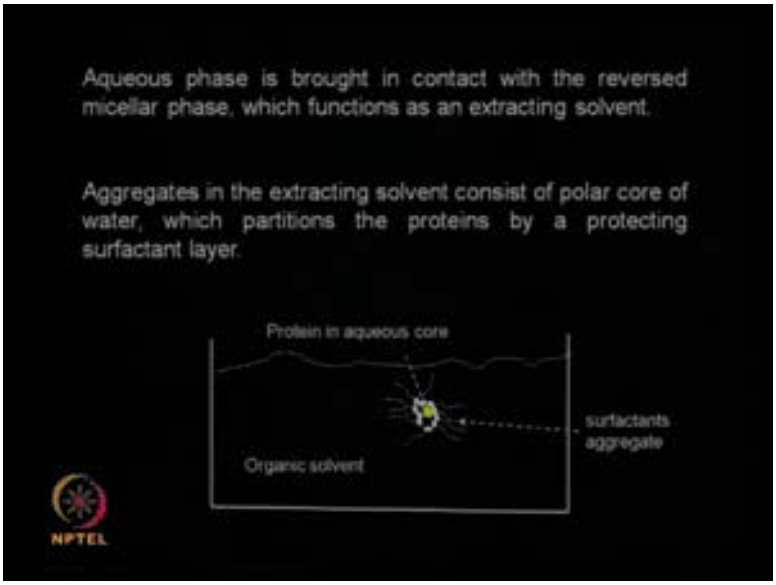

So, the surfactant can be used to selectively capture the protein of interest from the organic solvent. In fact, the surfactant keeps the proteins of interest away from the harsh solvent environment which may deactivate or denature your protein. So, what happens is there is a reverse Micellar situation that happens the surfactant aggregates. So, that the polar head groups or pointing inwards the hydrophobic tail is outside.

So, when the hydrophobic tail is outside it is in contact with your solvent whereas, when the polar head group is inside it captures not only your aqueous, water molecule it captures also the protein. And, so the protein is kept away from the organic solvent. This is what the aqueous 2 phase extraction system is as against the normal Solvent- Solvent extraction. Normal solvent solvents extraction systems are generally used for small molecules whereas we go use the reverse phase micellar system if you are requiring protein. In fact, that is what this particular picture tells about.

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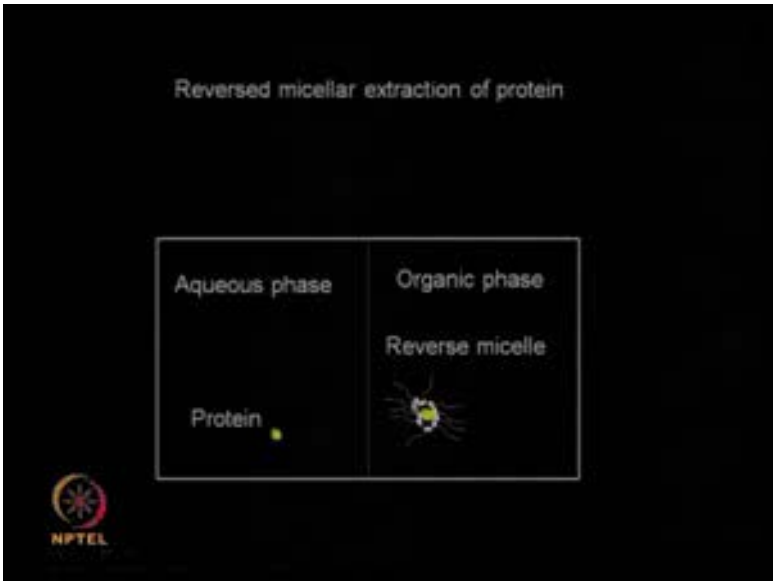

You have the protein and aqueous phase and once you add the organic phase and then the presence of surfactant a reverse micelle is formed. So, the protein is inside.

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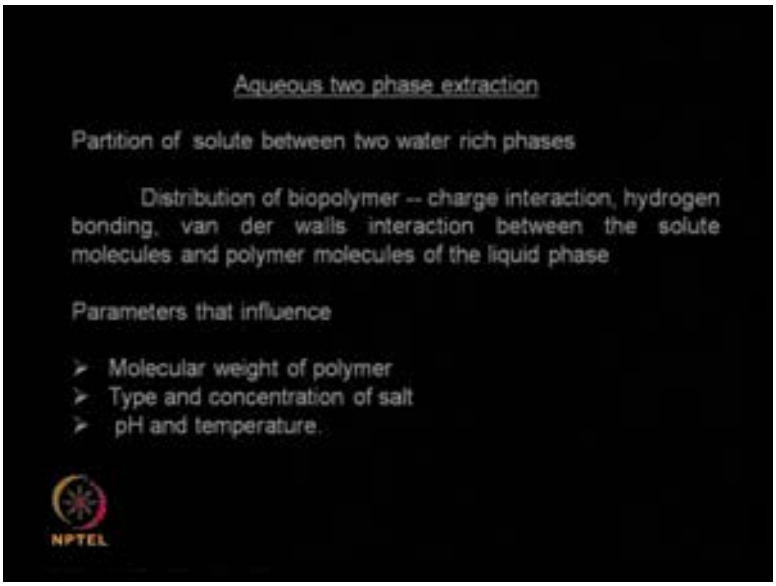

Another system which we talked about is aqueous 2 phase extraction; that means a you are extracting your desired protein from aqueous medium using water. So, it is a very interesting situation you have 2 both the systems the liquid systems are water. So, here you used something called a biopolymer. So, the biopolymer is present in this aqueous water which is going to be extracting.

So, depending upon the density of the biopolymer the partition coefficient of the solute of interest varies. So, if I keep increasing the density of the biopolymer then the solubility of the protein of interest goes down. So, if I keep the molecular weight of the biopolymer less than the solubility of the protein of interest increases. So, by manipulating the molecular weight of the biopolymer we can change the solubility or the partition coefficient of the protein of interest. And, also you can change the type of salt, concentration of salt, the Ph, temperature such operating conditions to modify the partition coefficient.

So, in this particular aqueous system 2 phase system you are having the solvent also water and the protein is also initially present in the water. So, for example if you are doing carrying out a fermentation. And, generally the fermentations are carried out in aqueous medium in the presence of salts, buffer and so on. You may have the biomass cell debris, broken cells and the metabolites, intracellular materials present.

Now, you want to selectively just remove all the cell debris, cell mass, biomass and so on. So, that is where you use a aqueous 2 phase extraction system actually. So, the interaction between the biopolymer and the protein of interest is through non bodied interaction like charge interaction, hydrogen bonding, Vander wall interaction and so on.

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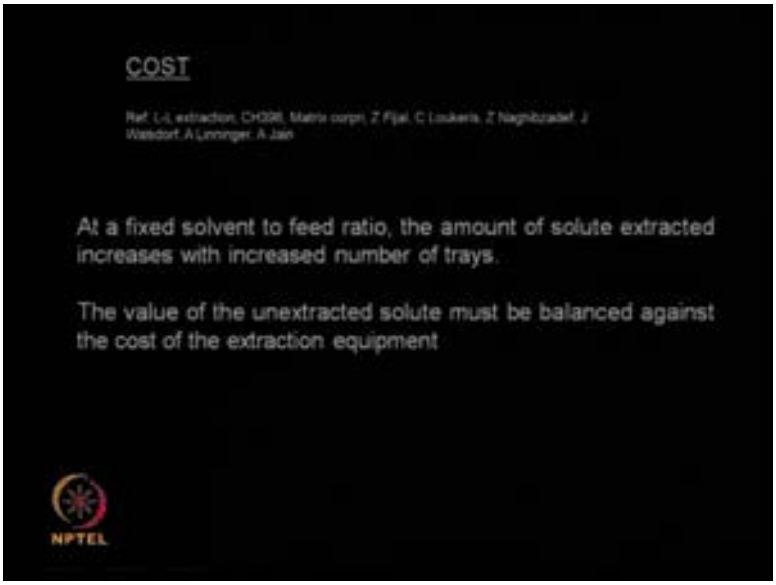

Now, let us look at a something called costing; ultimately when we want to decide on what type of equipment to use cost plays a very very important parameter or a factor;

yesterday I just introduced the concept of cost. Now, we will spend more time on the concept of cost. Here, before you do the costing you need to realize something we can modify the quantity of a solvent that I am uses it for extraction or we can increase the number of stages.

So, if you increasing the number of stages you are increasing the capital cost. If you are increasing the solvent amount you need to think about how to recover the solvent? That means, you are increasing your operating cost. In addition, if I am going to use large amount solvent then my vessels should be large enough to handle those quantity of solvent actually.

So, at a fixed solvent to feed ration the amount of solute that you are extracting will increase within number of trays; so it is obvious. So, if I keep on increasing trays I will be able to extract more of the solute from your mother liquor. But then the cost also increases because you are increasing the number of stages.

So, it depends on what is the value of that solute which you are extracting? If it is a bulk chemical you do not want to have extra stages and waste your capital cost whereas, the cost of the solute you are extracting might not be so much. But if it is a highly value added chemical and you want to extract as much as possible; then obviously you may increase the number of stages. So, you will be adding to the capital cost. But you will be making in the selling price of that total product.

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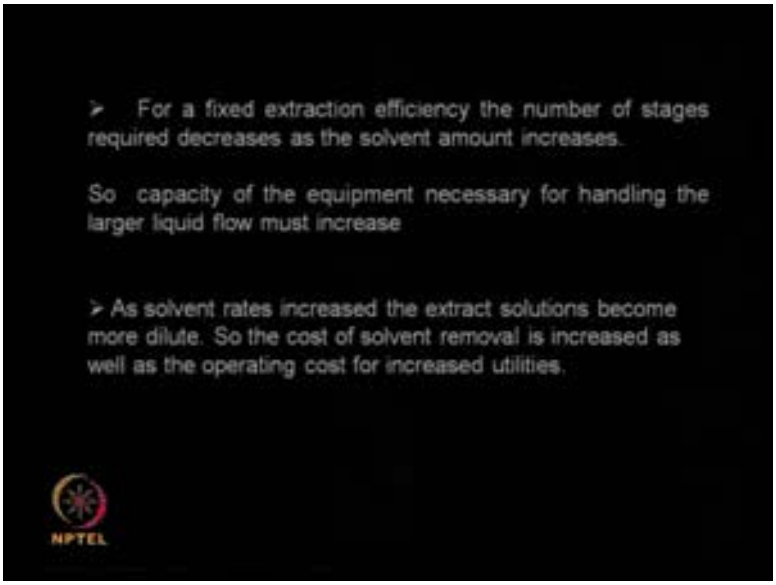

For a fixed extraction efficiency that means given a particular extraction efficiency. If I keep on increasing solvent amount obviously I will be able to reduce the number of stages. If I decrease solvent amount for fixed extraction efficiency I need to put in more stages it is obvious, right. So, if I am going to have more solvent amount obviously the capacity of the equipment also has to be very very large for handling that.

And, if I am having more solvent amount the product is in a very diluted form; so solvent removal cost needs to be included. So, the distillation column has to be larger may be the steam amount of steam required to distal out the material also increases. So, the operating cost, utility cost they all go up. So, you see that you need to again balance between do I put in more stages and do I have more quantity of solvent with less stages? So, again there is a balance.

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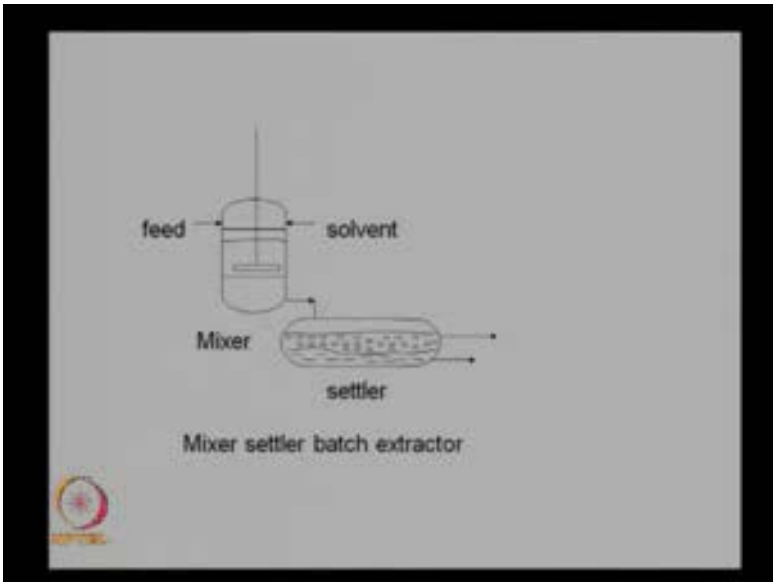

This is a typical mix settler if you remember very early about 4 or 5 classes back we talked about; where you have a tank, where you are mixing your feed and the solvent. So, that means; you have an agitator and you have a big tank. So, the quantity of the solvent you are handling, the quantity of the feed you are handling will determine the size of your mixer.

Now, if you look at the settler this is another tank where you are not using an agitator. So, the 2 phase is separate out. So, you take out the solvent phase and you take out the heavy phase; so that's the settler part. So, each mixer settler is like 1single stage. So, if

you are going to have 4 or 5 mix settlers to achieve 4 or 5 stages it is not very efficient, because you will be occupying a lot of space.

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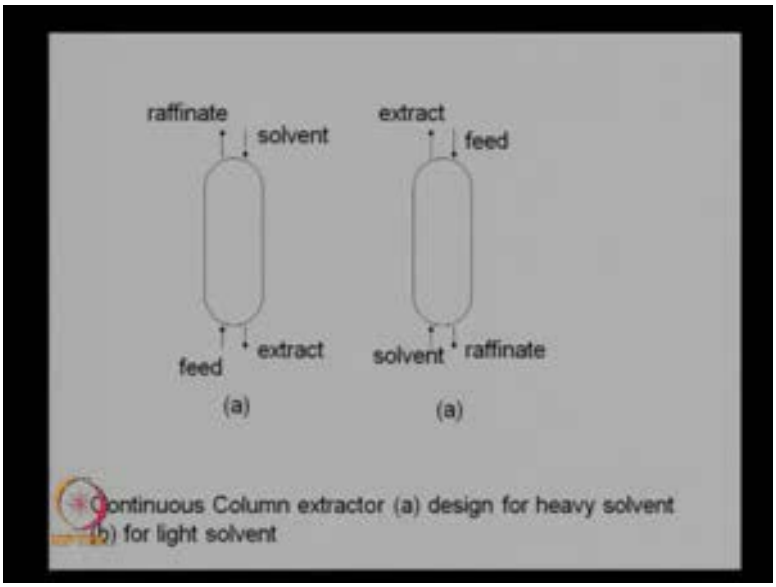

So, on the contrary you may go to a column type of a Liquid- Liquid Extraction. If you are talking about multiple stages the advantage here is you do not have a mechanical agitation you will be occupying less floor space because it is like a column. So, we can use it for heavy solvent, you can use it for light solvent. If you remember this particular figure from 4 classes back we can use this is a counter current system both for a heavy solvent as well as for the light solvent.

Here, indicates of heavy solvent; the solvent will be flowing from top to bottom whereas, in the case on light solvent you will be having the solvent flowing from bottom to top. So, each a type of equipment will have different type of capital cost different type of operating cost and so on. So, let us spend time little bit on the costing part.

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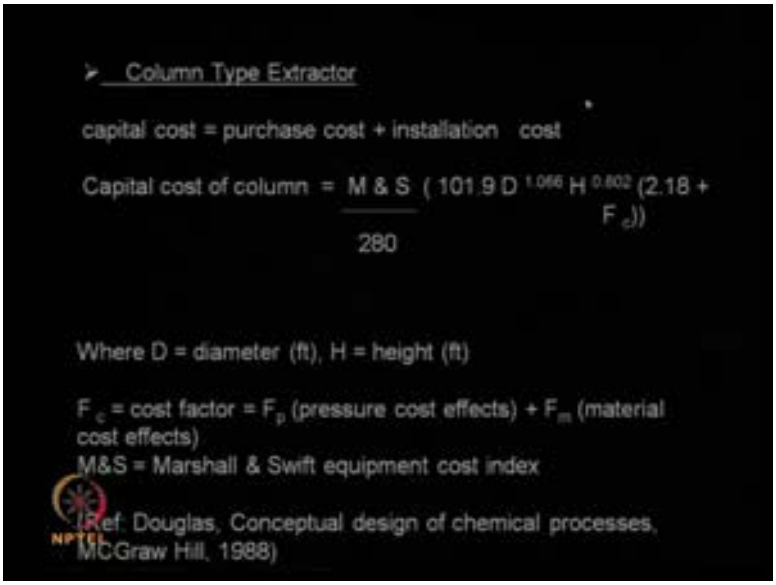

If you look at column type extractor it is not only the purchase cost of the column but it always include the installation cost. The instillation cost like I have been telling many times will depend upon preparing your land, erecting your structure, having electrical connections, having water connections, having insulation; so all these will add up to instillation cost.

So, a capital cost will include both you are making the column operational. So, that is what you are doing in his particular case. So, a capital cost will depend upon the column, parameter called M and S we will talk about this parameter. M and S is nothing but Marshall and swift equipment cost index. And, it is a function of the diameter of a column, it is a function of the height of the column and also something called the cost factor.

This cost factor will depend upon many parameters the pressure; that means the pressure you are operating and the material of construction of the internals, the type of internals you are using and so on. So, this particular formula was taken from a book called a Douglas conceptual design of chemical processes it is a 1988 book actually.

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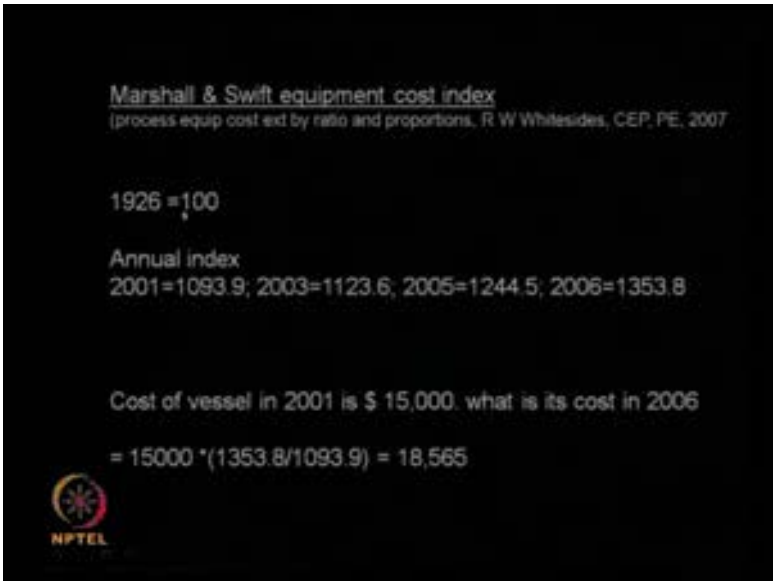

Now, the Marshall and swift equipment cost index. Let us spend little bit time on that. So, this cost index in the 1926 it is taken as 100 and then the cost for different time periods were calculated. For example, the M and S cost index for the year 2001 is 1093 and for 2006 it is a 1353. So, in 1926 it was 100 and in 2006 it is taken as 1353; so that includes things like inflation, purchasing power and so on actually. So, where do you use this number?

Look at this example, suppose I have some idea about a cost of the vessel in year 2001 it was 15000. Now, somebody is asking you what will be the approximate cost of that in 2006? What do you do? You go to the some chemical process industry data sheet or data base get the M and S equipment cost index for the 2001 which is 1093. And, for 2006 it is a 1353 the current, the 2001 prize is 15000.

So, 15000 into 1353 divided by 1093 will give you 18565. So, approximately the equipment will cost in the year 2006; 18565 dollars if it costed 15000 dollars in 2001. So, this is where we use the M and S equipment cost index, understand. So, we can use it for calculating the current prize; if you know the current M and S index based on old prize, if you know the M and S index for that particular year. Many chemical engineering and process engineering, data sheets or books keep giving the M and S values for quarters; so we can be more accurate. So, quarterly changes are also happening .So, the base for M and S is that in the year 1926 the cost index is taken as 100.

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Now, there is another equation which is relating the cost verses the size of the equipment. For example, if I know the cost of an equipment cost A whose size is known size A. And, I want to find the cost of an another equipment larger equipment, that is size B what will be the cost? So, this is the particular formula where cost B is equal to cost A multiplied by size B by size A raise to the power n; n is an exponent, that is called the size exponent. And, it varies between 0.3 to 1.72 for different type of equipments; if it is agitator you have different n value, if it is a tank it is different and so on.

There is a table I will show you the table. So, where do you use this? For example, I know the cost of a 2000 gallon vessel and I say it cost about a 15000 dollars; I want to know the cost of the vessel a 5000 gallon vessel, what will be the cost understand. A 2000 gallon vessel cost is known that is 15000 dollars.

Now, I want to know the cost of a 15000 gallon vessel. So, what do I do? 15000 is the cost of the smaller vessel, then size of the larger vessel is 5000, size of the small vessel is 2000 raise to the power n; in this particular case n is taken as 0.68, n for simple vessel is 0.68. So, when you calculate you get 27970, that means, a cost of a 5000 gallon vessel almost similar vessel is 27970 if the cost of a 2000 gallon vessel is 15000.

So, with these 2 formula we can do lot of equipment calculation which is good enough for a first order approximation, that means there could be almost 20 percent difference plus or minus variation. But it is good enough for us to make some decisions actually.

Now, I said this n value varies between 0.3 to 0.72. So, depending upon the type of equipment there are again tables available which tells you what n to select?

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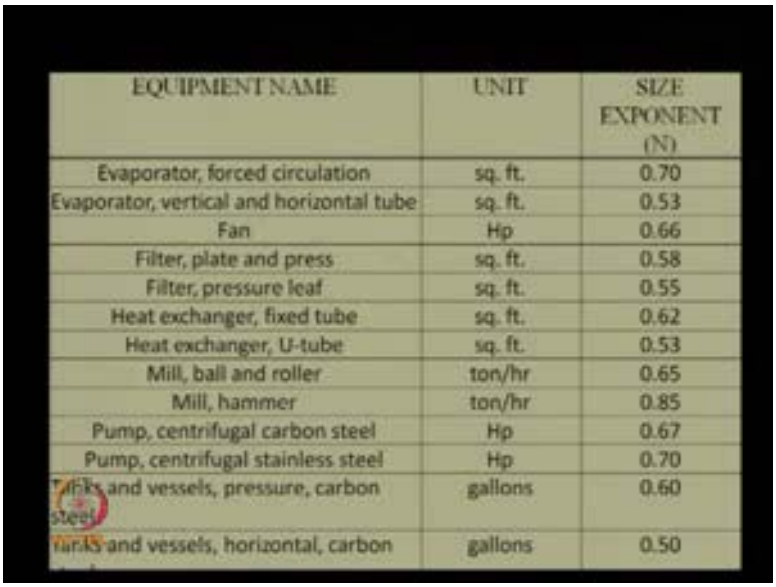

EQUIPMENT NAME	UNIT	SIZE EXPONENT (N)
Evaporator, forced circulation	sq. ft.	0.70
Evaporator, vertical and horizontal tube	sq. ft.	0.53
Fan	Hp	0.66
Filter, plate and press	sq. ft.	0.58
Filter, pressure leaf	sq. ft.	0.55
Heat exchanger, fixed tube	sq. ft.	0.62
Heat exchanger, U-tube	sq. ft.	0.53
Mill, 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

For example, if it is an agitator propeller type of agitator n is 0.5, if it is a turbine types it is 0.3 if it is compressor its 0.67, if it is boiler you see it is about 0.5 centrifuges going much higher than 1.72 it is a horizontal basket centrifuge. For conveyor belts you take values between 0.65 to 0.85, drier it go down to 0.45, that is drum type of drier collectors, dust collectors you have some values, evaporators you have some values like 0.7, filters 0.65 and so on.

Pumps you have 0.6, tanks about 0.6, again vessels 0.5 and so on. So, you see that there are data available which will give you some value for n. And, we can use that n in our equation to calculate the cost of an equipment which is larger than the original smaller equipment whose cost is known. So, we can use that particular equation to calculate cost of equipment. So, see cost some first order approximate cost could be obtained using these very simple formulae.

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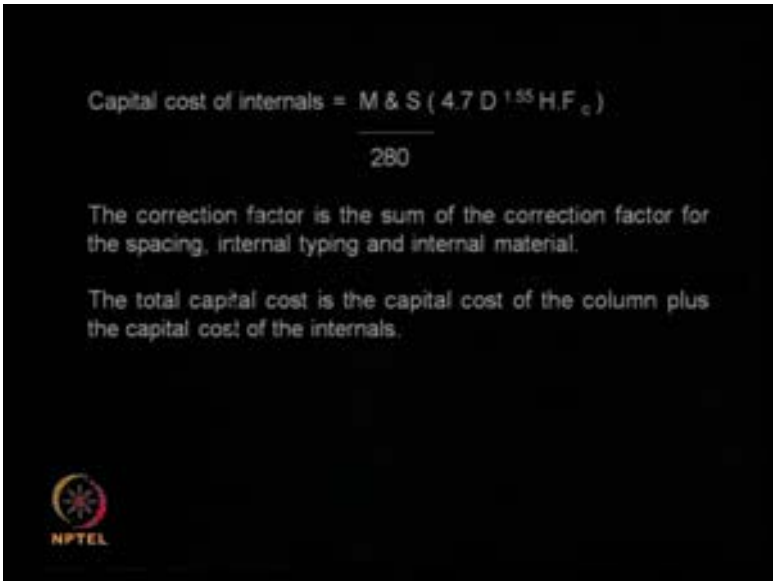

Now, a column extractor will also have internals, right. It can have a packing, it may have trays, it may have different type of material inside. So, we need to consider that also. So, you need to consider that in this particular equation again, you have M and S divided by 280 diameter of the column, height of the column and some you have the correction factor.

So, the correction factor will be function of spacing, inter type of internal, type of material of construction of the internal; you may have a stainless steel, you may have a mild steel, you may have a carbon steel so, depending upon that. So, the total capital cost will be capital cost of the column plus the capital cost of internals. Then, we include all the insulation cost. So, this gives you some idea about how to do a costing for a column type of extractor?

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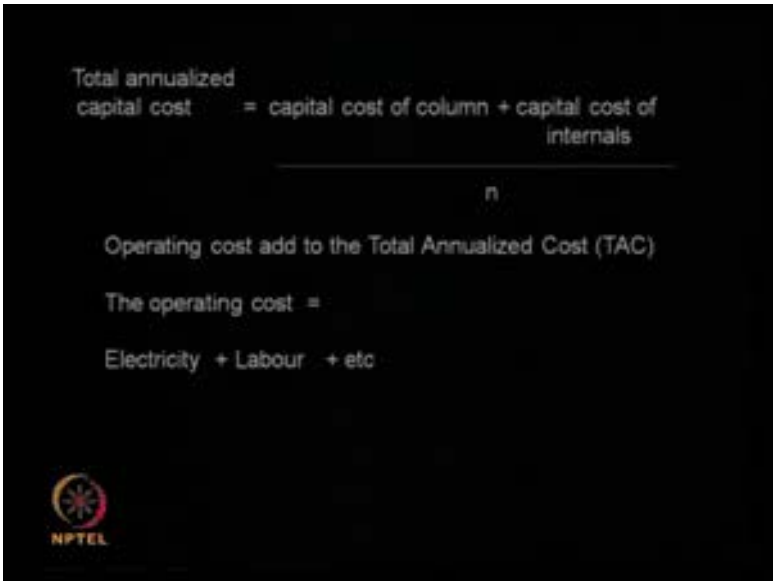

Now, there is something called annualized capital cost. Annualized capital cost I buy equipment today the equipment may last say 10 years. So, the total cost divided by 10 will give me the annualized cost; that means the cost is distributed over that period of n. Now, n varies depending upon the type of equipment so some chemical process equipments may last 5 years, some may last 10 years, some may last 15 years. So, you can annualize it by dividing with that corresponding number.

For example, even if you take a laptop for example, it may last for 3 years or 4 years or 5 years maximum 5 years. So, we can divide by that particular number whereas; if you take a reactor; it may last for 10 to 12 years. If you take a simple ordinary vessel without agitation it may last for 20 years, buildings may last for 20 to 25 years. So, the denominator will vary depending upon the life of the particular equipment. Now, the operating cost will involve electricity, labor, utilities like water, steam, chilled water and so on actually. So, all these needs to be considered in the operating cost.

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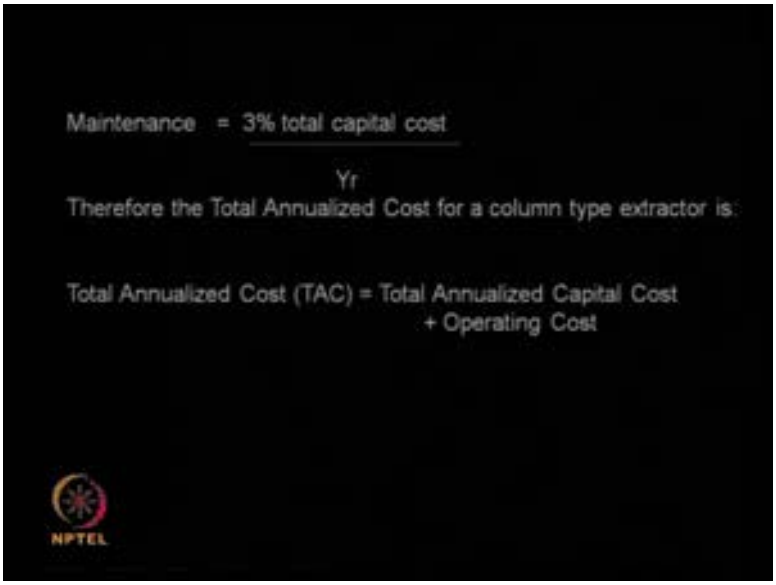

Now, there is something called maintenance also you need to consider that. Because every year you need to change some moving parts, you need to change some brushes, you need to change some gaskets, you may have to oil the equipment, you may have to take care of the wear and tear of some of the moving parts and so on. So, generally we may consider 3 percent of the total capital cost as a maintenance. So, even that needs to be added to calculate the total annualized cost.

So, you see so many factors come into picture you need to consider the actual equipment cost, the cost of the internals then cost of making it operational. And, then when you divide by the total life of the equipment that will give me annualized cost. Then, we need to consider the maintenance cost.

Now, here I am talking that the maintenance cost will be 3 percent of the capital cost. But it can vary it can become 5 percent or it can be even 10 percent depending upon the complexity of the equipment and so on actually.

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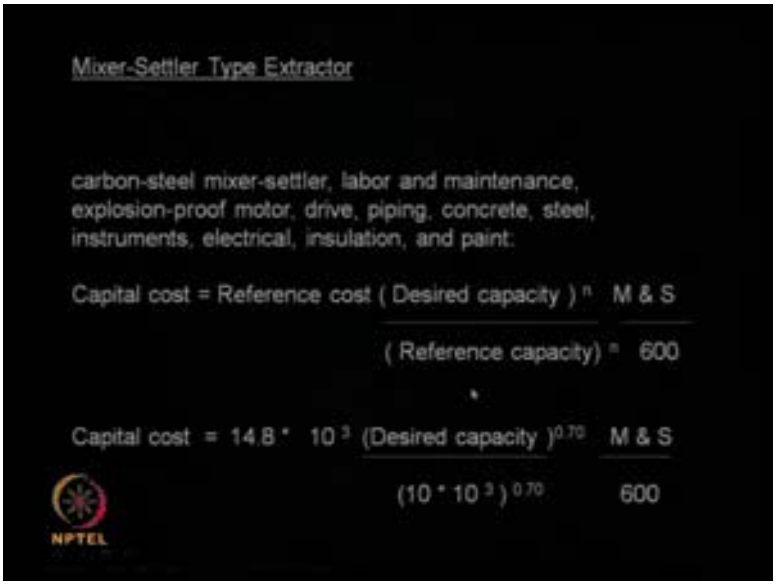

Let us go to mixer settler where you have a mixing taking place in a vessel; that means there is an agitator there in the mixer. And, then after the through mixing they are transferred to a vessel where they are allowed to stay put and the 2 phases get separated. So, in a mixer settler you can have a carbon steel mixer settler mostly we use very cheap material for mixer settler; unless you are worried about the type of material which is going to affect your final product actually.

So, in a mixer settler you have to consider labor maintenance, explosion proof motor. Because if you are talking about solvent which are highly vaporizing you need to consider the motor that there is a drive piping, concrete steel, instruments, electrical insulations, painting. So, all these factors need to be included when you are making your capital cost.

So, again in mixer settler we can have a reference cost, reference capacity, desired capacity, the exponent formula which I talked about. And, again there is a M and S coming into Marshall and swift index coming into picture. So, we can have formulae like this raise to the power 0.7 because if you are just talking about a simple tank with the agitator in the mixer settler. Then, we can use the exponent as 0.7 here; again you can use this simple formula for calculating the cost depending upon the capacity of the mixer settler.

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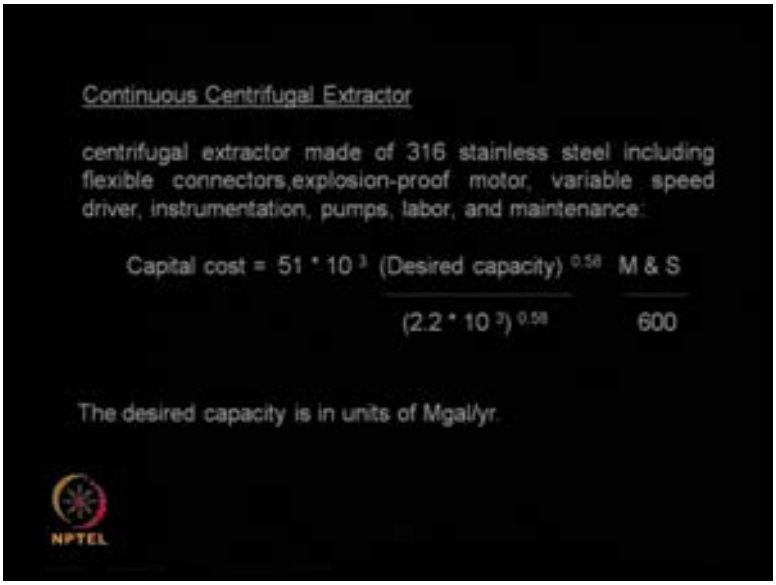

If you go to an extractor, centrifugal extractor then generally we use a 316 stainless steel. So, it is slightly expensive then it is going to have flexible connections explosion proof motor. Again, you are handling solvents means, vaporization of the solvent, explosion proof needs to be considered. Then, you will need a variable speed driver because the centrifuge RPM may be manipulatable.

Then, you have the instrumentation, you have the pumps, you have labor maintenance and so on. So, again you can have a formula like this here invert is the exponent is 0.58; again you have the Marshall and swift capital cost it coming in here. So, depending upon the capacity of your continuous centrifuge you can calculate the capital cost using this formula.

Here, the capacity is assumed as mega gallon per year. So,, you see lot of a numbers here these are all based on the indices, various indices which are used in chemical process industries. So, you see we talked about a several simple formulae which can be used to calculate the cost of different equipments that are going to be used in Liquid-Liquid Extraction. The basic types of equipments are mixer settlers, column type of extractors or centrifugal type of extractors.

Now, so far we talked quite a lot about the Liquid -Liquid Extraction in the past 5 to 6 classes a wide ranging Liquid- Liquid Extraction technique. The issues related to the Liquid- Liquid Extraction the solvent usage, the type of solvents and the conditions for

the solvents. And, then we looked at aqueous type of extraction and then we looked at the costing factors the various factors that add up to the cost.

And, whatever costing we talked about it is not a very detailed accurate costing. But it is more like a 25 percent error plus or minus 25 percent error costing. So, that is good enough to make a certain selections. But if you are interested to get a detailed costing; then you need to spend more effort and spend more time to actually do those costing. Now, having done that now let us move to the next topic, that is the membrane.

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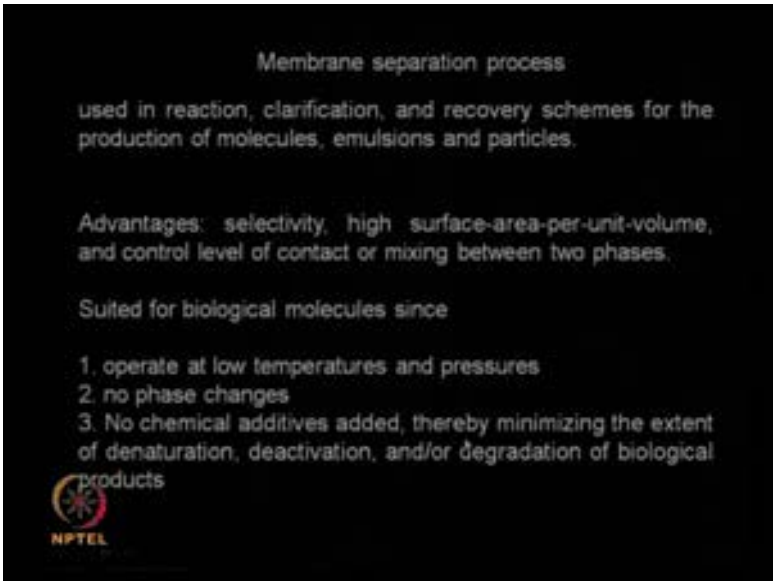

So, membrane is a very very important downstream technique, which is used for removing large solids, medium solids, micron size solids, liquids, broths, salts, dead cell mass, cell debris and so on. So, membrane has become extremely ubiquitous in downstream processing for a wide range of a chemicals, solids, biomass and so on actually.

So, it is used in reactions you can have a membrane bio reactors, membrane reactors it is used in clarification. That means, we can use it for separating out a repulsions and frothy material. It is used in recovery where you are trying to recover products of your interest; just a salt, mono salt from a large mixture of several salts. It can be used for removing water from ethanol; you want to purify ethanol to 100 percent. It can be used for getting portable water from waste water.

So, membranes are used everywhere now a days. And, it is become extremely useful for separating a wide range of chemicals, solids and cell debris. Membranes can be made very selective; there can be membranes which are selective for only water, there are membrane which are selective for solvents.

That means, you can have hydrophilic membranes, you can have hydrophobic membranes. You can have very large surface area per unit volume. So, we can have very good separation efficiencies, we can also have a good contact and also a good mixing between various phases. So, these are the main advantages of membranes.

So, it is they are suited for biological molecules because the separation can be done in ambient conditions. So, the biological molecules do not lose their activity. So, the membranes can be operated at low temperatures and ranging from vacuum right up to 40, 50 bar pressure.

Especially, the reverse osmosis membranes are operated at very very large pressure; where we can desalinate salt water. That means, you are marine water into portable water in fact countries like Southey Arabia use reverse osmosis membrane for preparing drinking water for the population from brackish marine salt water. Because they do not have any bore wells where they will get pure drinking water there are no phase changes.

Generally, there are no phase changes in membrane process. That means, if you have a liquid and a solid and you are removing the solid from the liquid there is no phase change; you are not adding chemicals to it. So, that means you do not have to worry about whether the additives you are adding is going to affect your protein or bio molecule or peptide. So, there is not going to be any denaturation or they are not going to have a deactivation or degradation of the biological process that is why membranes are very very useful.

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So, what is a membrane? Membrane is a polymeric material; it could be a bio polymeric, it could be a synthetic polymeric, it could have combination of both. Sometimes some in organic material is also added for strengthening or increasing selectivity. And, then it is used for separating out these various solid, liquid or Liquid- Liquid phases. So, they are always a thin barrier you do not have very very thick membrane generally, you have thin membranes.

So, what is the driving force in a membrane? It could be a concentration based driving force, it could be a pressure based driving force, it could be that is vacuum based, it could be a vapor pressure based driving force, it could be based on electrical chargers. So, there are so many different driving forces which can be used for separating out different material and that is the advantage.

For example, in electro dialyses where it is also called the artificial kidney where patient people who have a kidney failure; where the kidney does not help in separating out the salts and the urine from the normal blood they use membranes; where, they use certain electrical charge driving, electrical driving force for removing the salts from the blood. So, that the blood which contains urea and other salts is purified. So, the artificial kidney has membranes and they separate out the salts, ions from the blood. So, that the blood gets converted into purified blood. So, it does the job of a kidney.

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There are several types of membrane processes you have a microfiltration, Nano filtration, Ultra filtration, then we have the reverse osmosis, then we have the dialysis in the electro dialysis, then we have the pervaporation. So, large number of a membrane processes and they are become industrially important. And, many of these which I am talking about in this slide are already being practiced in a very large industrial scale.

So, they are it is not academic exercise but it is being practiced in commercial settings. So, microfiltration, ultra filtration. So, you are purifying aqueous streams. So, you can use it for removal of unwanted solids or you can use it for concentrating. That means, you have a very very thin liquid, you are removing a large amount of liquid.

So, that you are concentrating the slurry you can use it for recovery of valuable products. So, all these are done in microfiltration and ultra filtration. Look at reverse osmosis we can remove minerals, we can remove mono- valent cations and anions. And, so you make portable drinking water pure from anions and cations; we can remove bacteria, we can remove all the biological contaminants using reverse osmosis.

Electro dialysis we can use it for concentration or removal of dissolved ions. So, we can remove ions which are charged by applying large electric force or electric field. Gas separations we can use membranes for separating gases, we can remove unwanted gases from wanted gases by using selective membranes.

Pervaporation we can use it for concentrating liquid mixtures. Suppose, we have ethanol water I want to concentrate ethanol to 100 percent then I can use a pervaporation. Normally, ethanol water we cannot purify ethanol to 100 percent through distillation because ethanol water forms an isotope. So, at that isotope further purification or removal of water from ethanol is not possible.

So, in that situation what do we do either you add another solvent which will break the isotope. So, that you can purify ethanol but that has got disadvantage because you are adding another solvent which may be contaminating your system or which is also adding to the cost. So, here we use something called pervoparation.

So, we can use membranes which are hydrophilic; so that water alone can be just removed from ethanol. So, the ethanol can be concentrated to 100 percent; so pervoparation you use in such situation. Some time you want to concentrate fruit juices you do not want to heat it because fruit juice will lose its flavor, texture, color. So, there you use pervoparation. So, such situations pervoparation has become very very useful.

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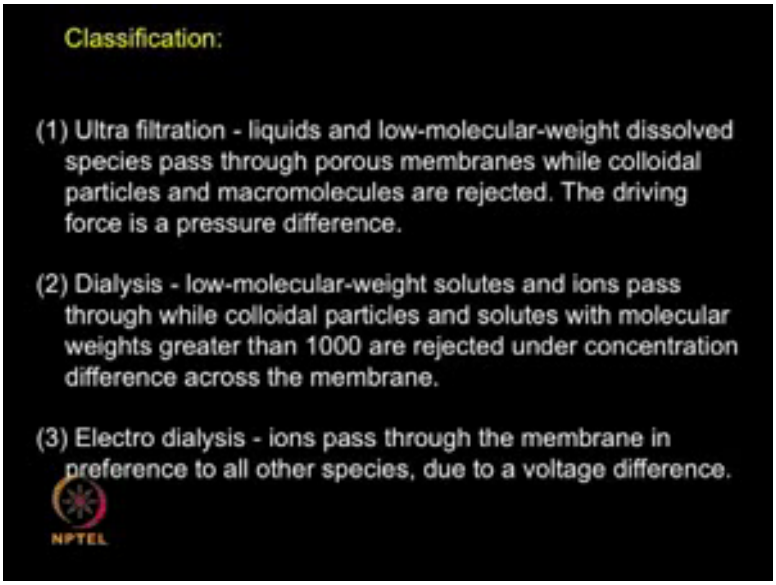

Ultra filtration. So, where do you use ultra filtration? So, we can use it for liquids and low molecular weight dissolved species, collide particles, macro molecules they can be rejected or captured. So, here the driving force is the pressure; so it is almost like a normal filter. So, there are holes, molecules or salt which are larger than the holes get rejected only the liquid goes through.

Dialysis there are membranes where again low molecular with solids and ion pass through in dialysis membrane where, colloidal particles solutes with molecular weight larger than 1000 are rejected. So, dialysis works on concentration difference across the membrane. So, you have large concentration in one side, you have low concentration in another side. So, the solute travels from the large concentration down to the low concentration.

Then, comes electro dialysis this happens because of a voltage difference. So, you are applying a voltage. So, cations will go to the cathode, anions will go to the anode; so that way ions get separated. So, the here the driving force is electrical feed whereas, in dialysis the driving force is the concentration gradient.

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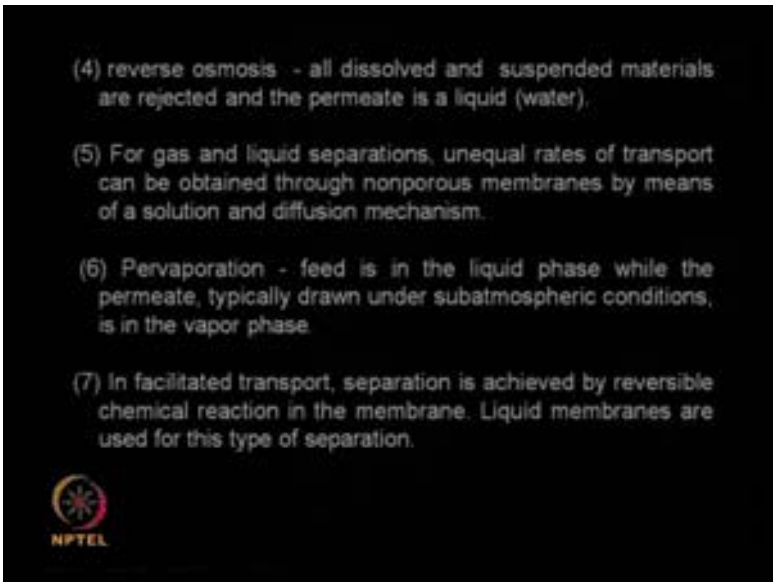

Reverse osmosis this can be used for dissolved and suspended material which will get rejected. So, you will get pure 100 percent pure water on the other side it is good for preparing drinking water. That means, you can completely remove all the salts present in the water. So, here the driving force is you are applying a pressure larger than the osmotic pressure.

So, that the water moves from a higher concentration to the lower concentration. For gas liquid separations again you may have unequal rates of transport through a nonporous membrane that means; if there are 2 gases; 1 gas may have a higher rate of transport in a nonporous membrane because of a solution and diffusion. That means; 1 gas defuses

faster whereas, other gas defuses slower. So, the faster gas which is defusing will be getting concentrated on the other side of the membrane. So, the gas liquid separation is not based on pores but it is based on diffusion phenomena.

Pervoparation the feed in the liquid phase will become vaporized they will permeate. And, they get captured or collected on the other side where you have lower pressure or the sub atmospheric pressure in the vapor phase. So, the feed liquid gets vaporized and the vapor selectively gets permeating through the membrane material and goes to the other side as a vapor.

So, here again you do not have pores in the membrane but the movement of the solute is through diffusion. Then, you can also have liquid membranes which can collect solutes of interest inside the liquid membrane.

So, there are so many different types of membrane techniques available. And, each technique operates on different principal; it could be a concentration gradient, it could be a pressure gradient, it could be osmotic pressure, it could be a ionic forces, it could be a large electromotive force applied, it could because of the rate at which certain material defuses through. And, all because of all these reasons you can get a separation. And, generally as I said membranes are thin material it could be hydrophilic or hydrophobic in nature.

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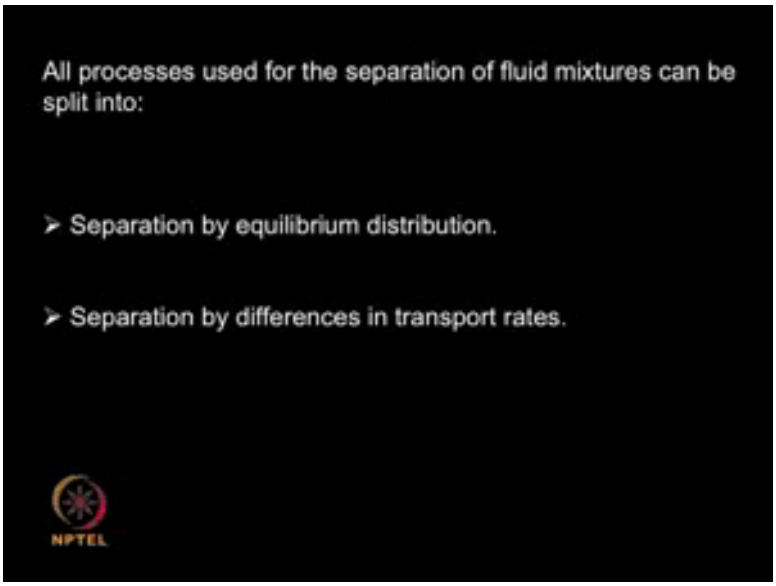

So, all the processes in the membrane separation happens because of a separation by equilibrium distribution or separation because of the transport rates. That means, one travels faster when compared to the other a substance. So, that is the transport in the other one is because of the equilibrium separations.

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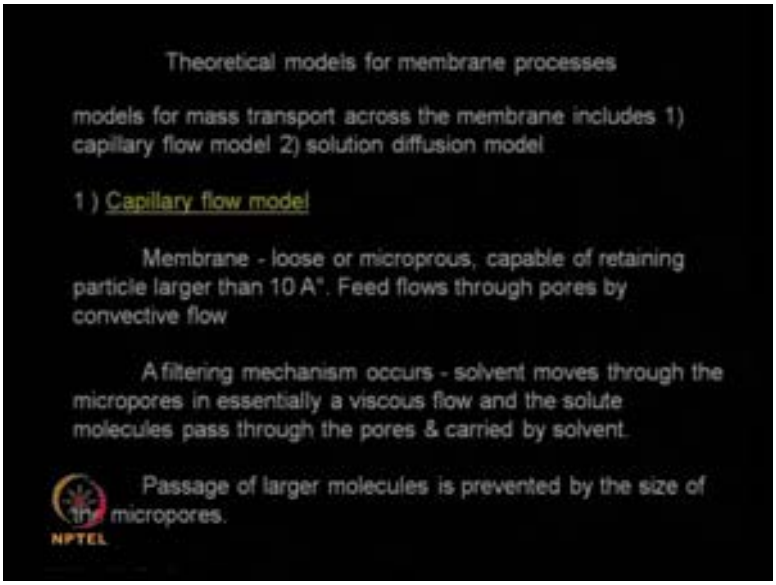

There are several models available for studying the membrane process. But 2 important models I will discuss little bit in detail; one is called the capillary low model the other is called the solution diffusion model. So, most of the membrane processes could be clubbed under this concept capillary flow model, another is the solution diffusion model. Capillary flow as the name implies you have loose microprous material inside liquid feed flows through the pores.

So, larger particle that means particle of about 10 angstroms are held back. And, the solution of the solvent flows through pores in a tortuous way and if there are particles which are very very small they travel with the solvent material. So, it is like a filtering mechanism. So, the solvent moves through the micro pores, through a viscous flow, solute molecules pass through the pores and carry it by the solvent whereas larger molecules get retained because of the size. So, that is called the capillary flow model.

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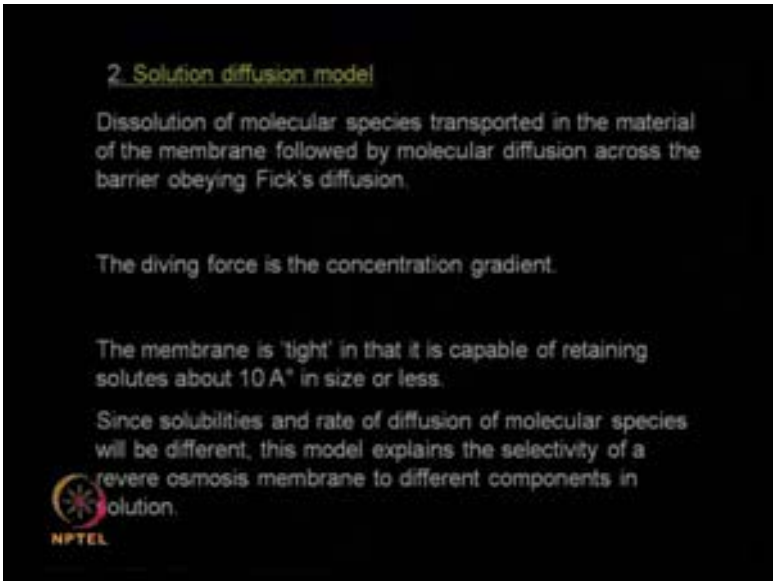

The next model is called the solution diffusion model. So, here what happens the molecules dissolves and the transportation through the membrane is because of the molecular diffusion. And, it is obeying the Fick's law of diffusion; so here the driving force is the concentration. So, he in this model it is assumed that the membrane is stick or tied or nonporous there are no pores here.

The material transport happens because of a disillusion of the solute and transportation because of the diffusion. So, the rate of diffusion of the solute determines the separation efficiency. So, this type of model is very very good for explaining reverse osmosis even pervoparation whereas, the capillary diffusion model is very good for ultra filtration and microfiltration and so on actually. So, in real life you may be using either the capillary flow model that is model 1 or the solution diffusion model to understand the process of separation very simple.

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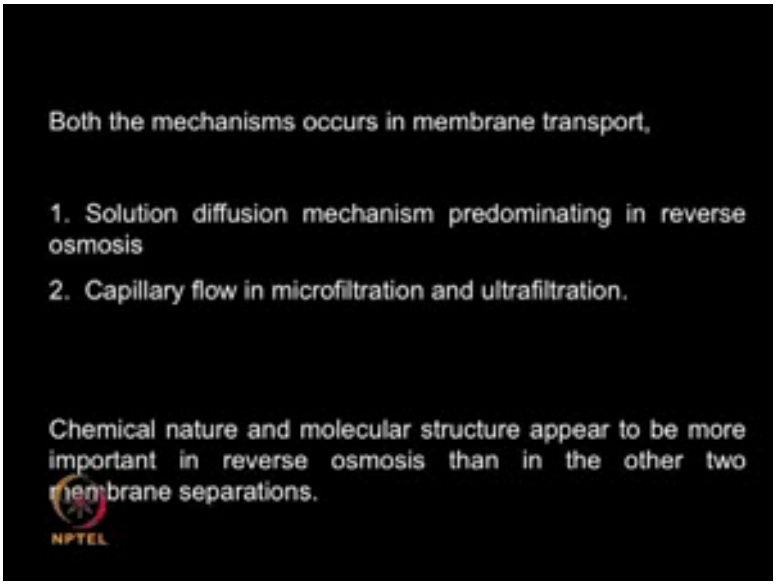

So, if you look at reverse osmosis mostly you will have diffusion mechanism taking place whereas, if you will take microfiltration or ultra filtration you will be having capillary flow taking place. So, the chemical nature structure of the molecule all these will come important in a diffusion process. So, in a reverse osmosis all these will play a very very important role, the size of the molecule, the diffusion coefficient of the molecule, rate of diffusion all these will play a important role. So, in that particular situation will use the diffusion model not the capillary flow model.

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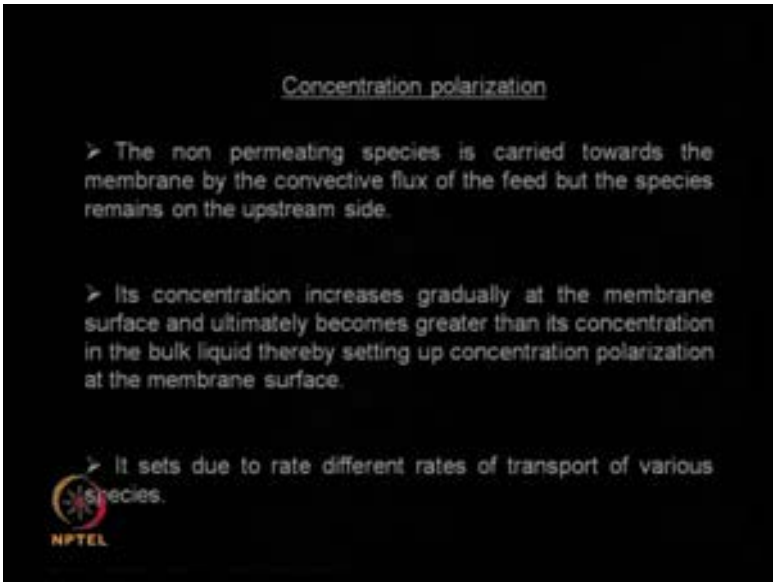

There is something very very important that happens in a membrane process; that is called the concentration polarization. What happens is you have many species inside the original mother liquor. And, as the liquid flows perpendicular to the membrane you will have the solvent and liquid, that is diffusing through and the solute molecule which are very very small will pass through the membrane. So, there are material which do not pass through will start accumulating on the upstream of the membrane. So, these its concentrations keep increasing; and gradually the membrane surface becomes highly concentrated with the solutes which do not pass through the membrane.

So, there is going to be a difference in the rate of a transport of various species when we consider the bulk concentration of the species vice versa the concentration of the species nears the upstream of the membrane surface; there is going to be lot of difference in this concentration and that is called the concentration polarization. Because of concentration polarization the rate of filtration also keeps going down. Because initially whatever, concentration of the solute in the bulk as well as the concentration of solute near the upstream of the membrane will be almost same.

But, as you keep doing performing the filtration process, as the solute molecules get accumulated on the upstream the concentration near the upstream of the membrane is going to be much higher than the bulk. So, the rate of filtration or the efficiency of the filtration is going to go down. This is what is called the concentration polarization.

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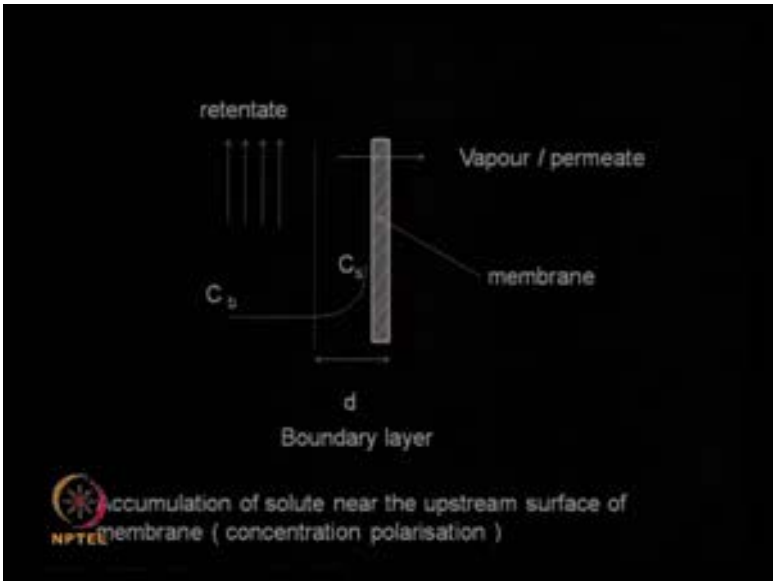

And, this is shown pictorially. For example, we have the vapor or the fluid flowing through the membrane material perpendicularly. So, whatever is there on the upstream that is called the retentate and whatever is on the downstream that is called the permeate there is always going to be a boundary layer. So, the concentration of the species in the bulk is C b concentration of the species near the upstream side near the membrane will be much higher and that is called C s.

And, C s is going to be much larger than C b. So, this is going to prevent the movement of C b species itself. Now, this accumulation of the solute near the upstream surface is called the concentration polarization. And, that depends also on several parameters like the properties of the solute, the viscosity of the solvent, the boundary layer that is formed and so on actually.

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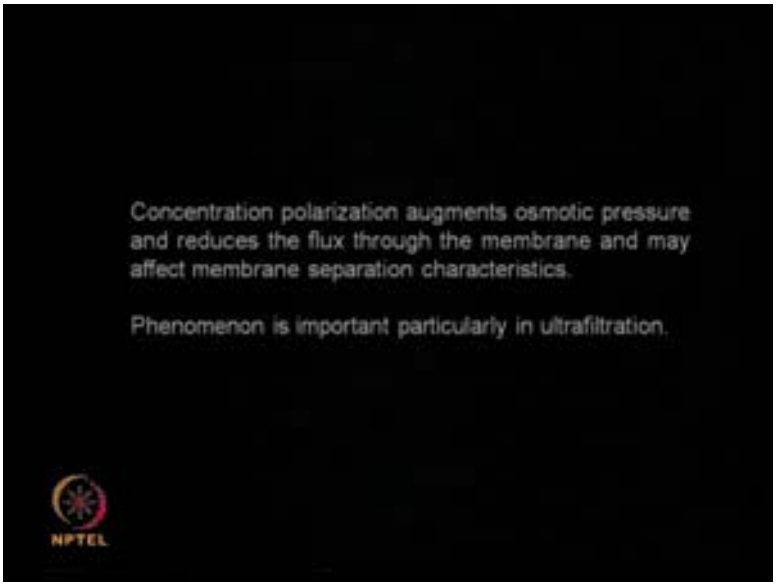

So, concentration polarization reduces the flux through the membrane. And, it will affect the membrane separation characteristics this becomes very very important in ultra filtration type situation. So, what do we do? We need to stop the entire process and again restart the whole thing. It is a reversible of course, it is not like an irreversible fowling of the membrane material it is reversible; but it is slowly going to slow down your separation process.

So, if you look at again this; the concentration in the bulk will be much lower in the concentration of the solute near the surface. And, this concentration is going to slow

down your filtration process and this will becomes very serious as you keep on doing the filtration.

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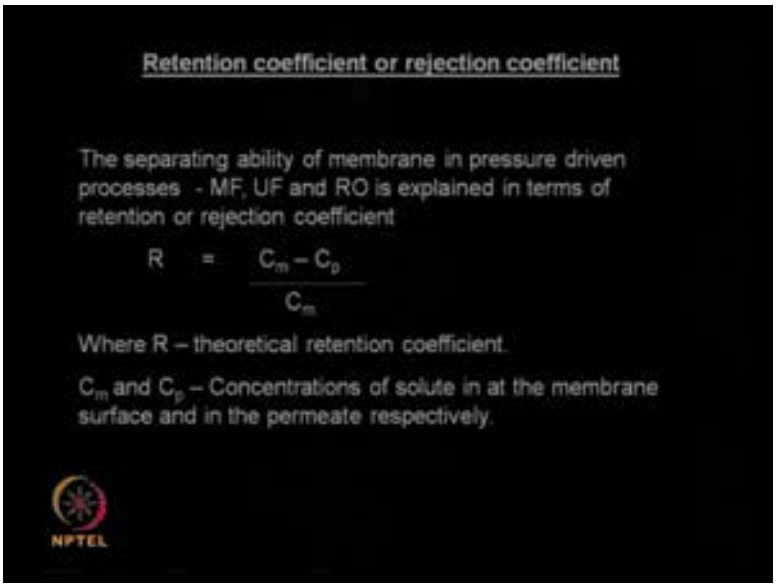

So, there is something called the retention coefficient or rejection coefficient we need to understand what retention coefficient is? And, what is rejection coefficient is? The separating ability of membrane in pressure driven process like microfiltration, ultra filtration, reverse osmosis and so on is based on something called a rejection coefficient.

So, rejection coefficient is nothing but concentration of the solute in the membrane surface minus concentration in the permeate divided by C m. So, obviously rejection coefficient will always be less than 1 agreed obvious. Please note R is depending upon C m. C m is the concentration of the solute in the membrane surface but it is not the concentration in the bulk of the upstream.

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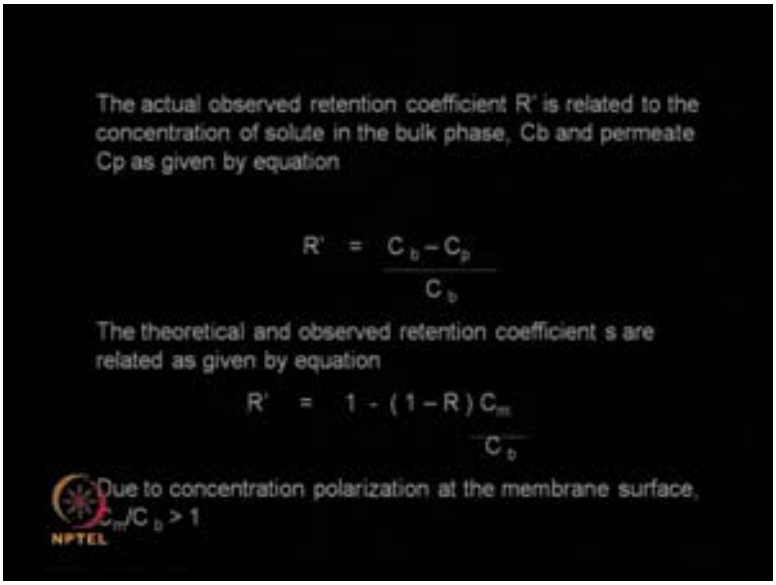

So, you can have another term caller R dash which is the actual observed retention coefficient. Now, this R dash is based on C b, that is the concentration of the permeate in the bulk phase. And, we just talked about the concept of concentration polarization; and we also said C b will not be same as the concentration in the upstream very close to the membrane; the upstream very close to the membrane concentration must be much higher than C b, right.

So, we have now defined 2 different retention coefficient or rejection coefficient. one is called R, other is called R dot, R dash. R dash is based on what we actually observe? It is based on the C b, that is the concentration in the bulk minus C p, that is; the concentration in the permeate divided by C b. So, by combining both we can get R dash is equal to 1 minus R C m by C b.

Now, C b is the concentration in the bulk, C m is the concentration near the upstream of the membrane. And, because of concentration polarization this term is always larger than 1 understand. This term is always larger than 1; if this term is equal to 1 what will happen? R dash will be equal to R understand this term is equal to 1. So, this will become 1 minus 1 plus R. So, 1 and minus 1 will cancel.

So, R dash will be R but because C m is larger than C b; R dash will be very different from R. So, you need to keep that point in mind. So, depending upon the concentration

polarization what the retention coefficient or rejection coefficient actually observed will be very different from the theoretical retention coefficient or rejection coefficient ok.