Plant Design and Economics

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Lecture No -45
Azeotropic Distillation Methods and Cost Estimation

Welcome to lecture 45 of plant design in economics in this last lecture of module 9, we will talk about few methods for azeotropic distillation and also will go through the cost estimation for distillation columns.

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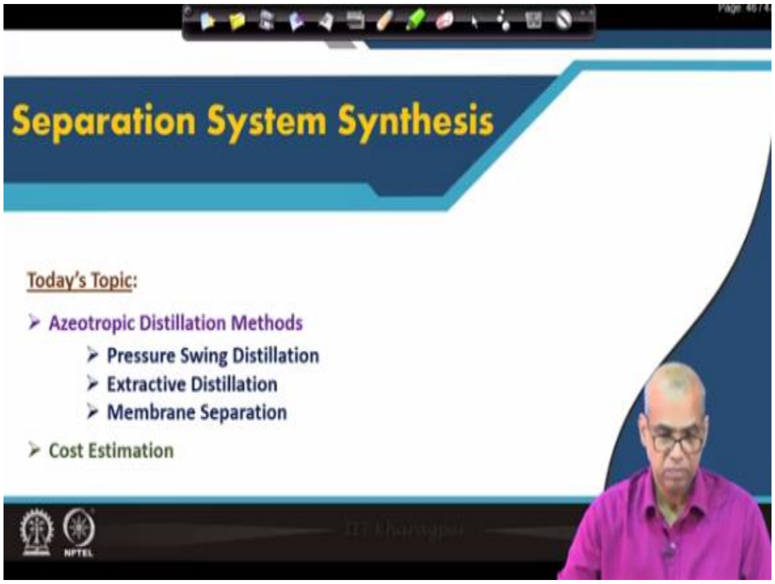

Separation System Synthesis

Today's Topic:

- Azeotropic Distillation Methods
  - Pressure Swing Distillation
  - Extractive Distillation
  - Membrane Separation
- Cost Estimation

So we will talk about 3 different methods for azeotropic distillations, pressure swing distillation, extractive distillation and membrane separation and then we will discuss cost estimation for distillation columns or a separation by distillation sequence.

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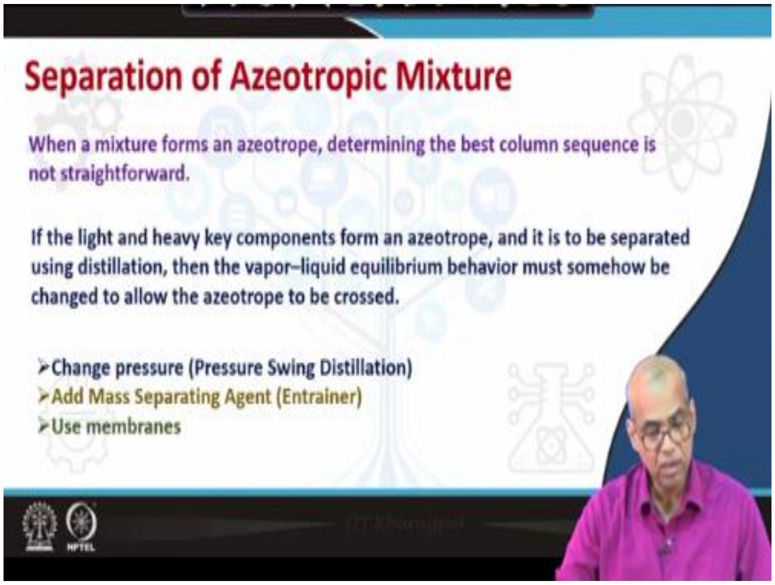

Separation of Azeotropic Mixture

When a mixture forms an azeotrope, determining the best column sequence is not straightforward.

If the light and heavy key components form an azeotrope, and it is to be separated using distillation, then the vapor–liquid equilibrium behavior must somehow be changed to allow the azeotrope to be crossed.

- Change pressure (Pressure Swing Distillation)
- Add Mass Separating Agent (Entrainer)
- Use membranes

When a mixture forms an isotope determining the based column sequence is not straight forward if the light and heavy key components form an azeotrope and it is to be separated using distillation only then the vapour liquid equilibrium behavior must somehow be changed to allow the azeotrope to be crossed and three different methods that we will discuss here can be used change of pressure to cross the azeotrope which is known as pressure swing distillation.

We can add a mass separating agent we call it entrainer here and we call so use membranes for azeotropic separation.

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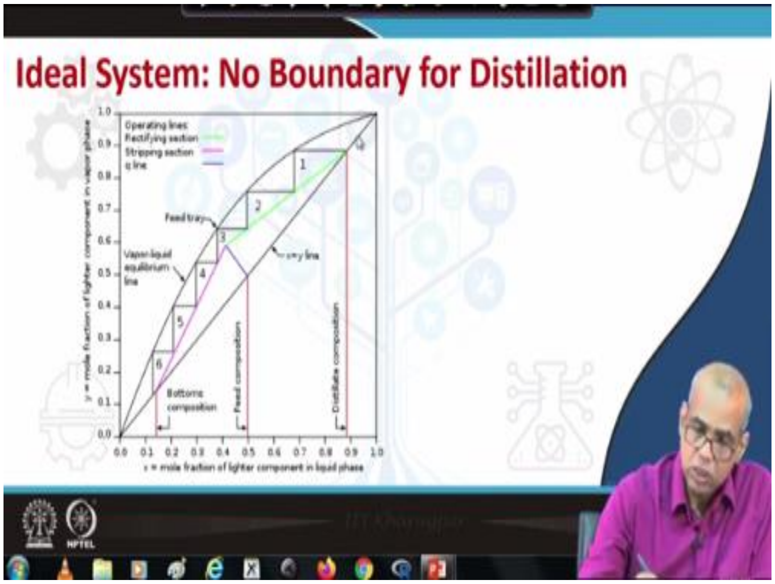

Ideal System: No Boundary for Distillation

If you look at the separation of an ideal mixture by distillation you see that there is no boundary for distillation. It is clear from this Mccabe Thiele diagram for binary mixtures that you can place the X D and X V as pure as you want. Of course there may be requirement for large number of trays because the spaces between the equilibrium curve and the operating lines were here will be very very small.

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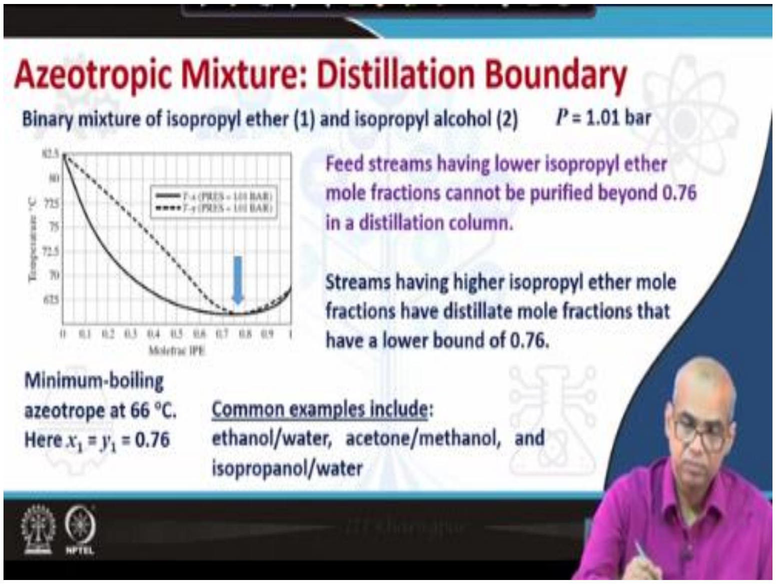

Azeotropic Mixture: Distillation Boundary

Binary mixture of isopropyl ether (1) and isopropyl alcohol (2) $P = 1.01$ bar

Feed streams having lower isopropyl ether mole fractions cannot be purified beyond 0.76 in a distillation column.

Streams having higher isopropyl ether mole fractions have distillate mole fractions that have a lower bound of 0.76.

Minimum-boiling azeotrope at 66 °C. Here $x_1 = y_1 = 0.76$

Common examples include: ethanol/water, acetone/methanol, and isopropanol/water

However there is actually no boundary for distillation but this is not the case when we have an azeotropic mixture there exist our distillation boundary both for Minimum boiling azeotrope as well as maximum boiling azeotrope. For example let us consider this minimum boiling azeotrope that is formed in case of isopropyl ether and isopropyl alcohol at 1.01 bar pressure.

The minimum boiling azeotrope is formed at 66 degrees Celsius and this boils with liquid phase and vapour phase composition as 0.76. So if we have heat streams having lower isopropyl ether mole fractions we cannot purify it beyond point 0.76 in a distillation column because otherwise it will require us to cross this boundary posed by the isotropic point. Similarly if I have streams having higher isopropyl ether mole fractions this will have displayed mole fractions lower bound as 0.76.

Some other common examples for minimum boiling azeotropes are ethanol water, acetone methanol, isopropanol water etcetera.

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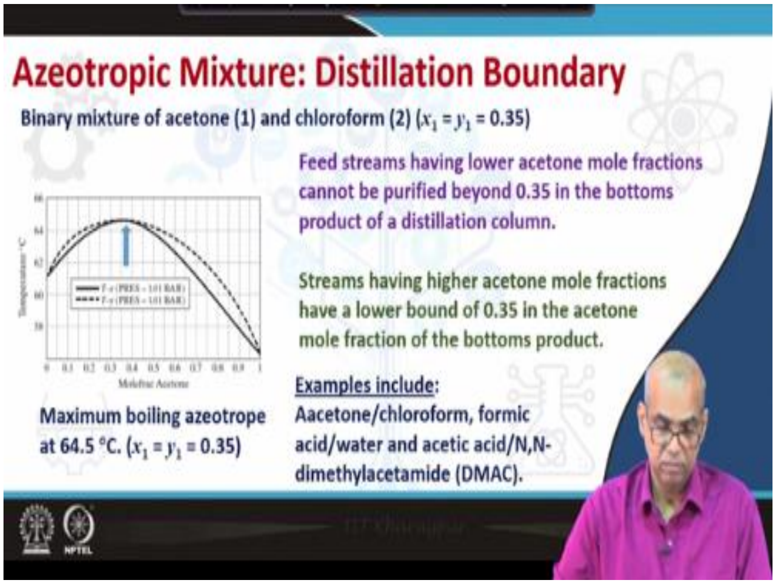

Azeotropic Mixture: Distillation Boundary

Binary mixture of acetone (1) and chloroform (2) ($x_1 = y_1 = 0.35$)

Maximum boiling azeotrope at 64.5 °C. ($x_1 = y_1 = 0.35$)

Feed streams having lower acetone mole fractions cannot be purified beyond 0.35 in the bottoms product of a distillation column.

Streams having higher acetone mole fractions have a lower bound of 0.35 in the acetone mole fraction of the bottoms product.

Examples include:
Aacetone/chloroform, formic acid/water and acetic acid/N,N-dimethylacetamide (DMAC).

Similarly let us take case of acetone and chloroform which forms a maximum boiling binary azeotrope at 64.5 degree celsius and these boils with liquid phase and vapor phase composition at 0.35. Now this is the maximum boiling azeotrope. So if we have feed streams having lower acetone mole fractions that cannot be purified beyond 0.35 in the bottom product of a distillation column.

Similarly streams having higher acetone mole fractions have a lower bound of 0.35 in the acetone mole fractions of the bottom product.

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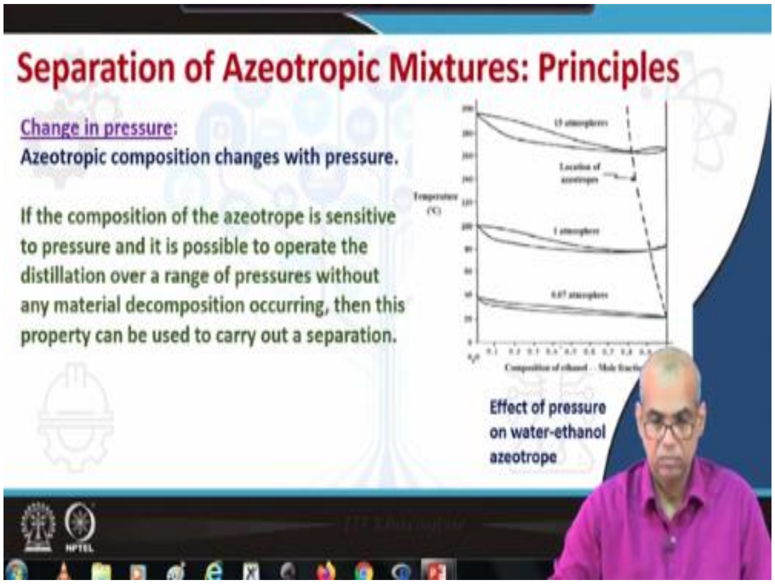

Separation of Azeotropic Mixtures: Principles

Change in pressure:
Azeotropic composition changes with pressure.

If the composition of the azeotrope is sensitive to pressure and it is possible to operate the distillation over a range of pressures without any material decomposition occurring, then this property can be used to carry out a separation.

Effect of pressure on water-ethanol azeotrope

Now let us look at the principles of those three separation methods for azeotropic mixtures; change of pressure, use of master separating agent or internal and use of membranes. Let us start with change in pressure, azeotropic composition changes with pressure. What is seen the figure is effect of pressure on water ethanol azeotropes. Note the shift in the azeotropic composition as we decrease pressure from 15 atmosphere to 1 atmosphere to 0.07 atmosphere.

So when you come to 0.07 atmosphere the azeotrope is gone, so the composition of the azeotrope is sensitive to pressure and it is possible to operate the distillation over a range of pressures without any material decomposition occurring then we can make use of this property to carry out a separation. A change in azeotropic composition of at least 5% with the change in pressure is usually required.

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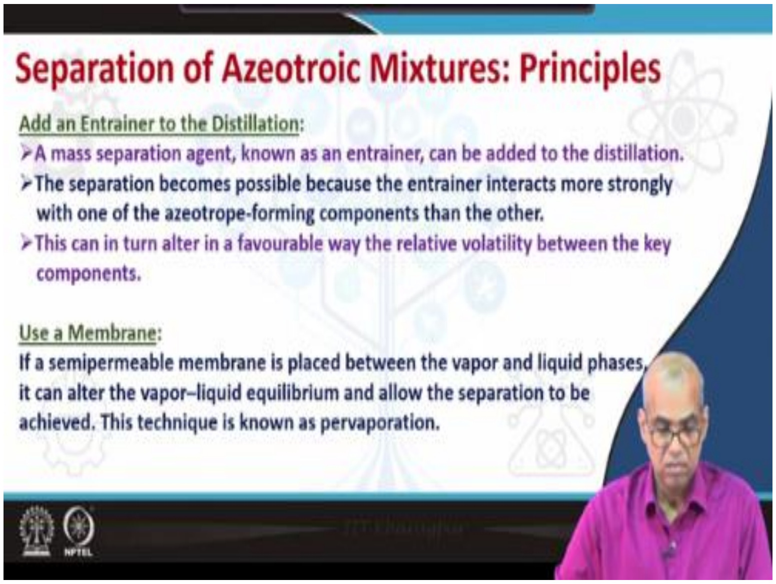

Separation of Azeotroic Mixtures: Principles

Add an Entrainer to the Distillation:

- A mass separation agent, known as an entrainer, can be added to the distillation.
- The separation becomes possible because the entrainer interacts more strongly with one of the azeotrope-forming components than the other.
- This can in turn alter in a favourable way the relative volatility between the key components.

Use a Membrane:

If a semipermeable membrane is placed between the vapor and liquid phases, it can alter the vapor–liquid equilibrium and allow the separation to be achieved. This technique is known as pervaporation.

Let us look at the principles for addition of mass separating agent or entrainer, a mass separating agent known as entrainer can be added to the distillation the separation becomes possible because the entrainer interacts more strongly with one of the azeotrope forming components than the other, this can in turn alter in a favorable way the relative volatility between the key components and then the separation becomes possible.

In case of membrane use if a semipermeable membrane is placed between the vapor and liquid phases it can alter the vapor liquid equilibrium and allow the separation to be achieved. This technique is known as pervaporation.

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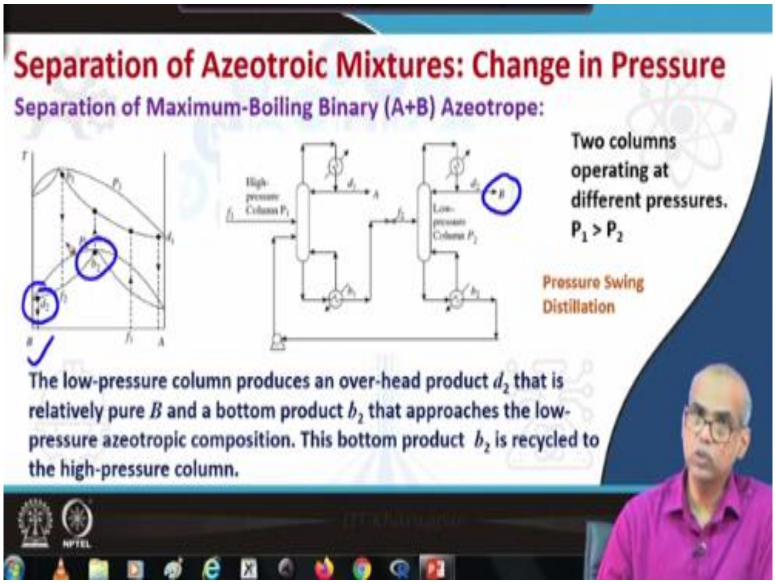

Separation of Azeotroic Mixtures: Change in Pressure

Separation of Maximum-Boiling Binary (A+B) Azeotrope:

Two columns operating at different pressures. $P_1 > P_2$

Pressure Swing Distillation

The low-pressure column produces an over-head product d_2 that is relatively pure B and a bottom product b_2 that approaches the low-pressure azeotropic composition. This bottom product b_2 is recycled to the high-pressure column.

Let us start with separation of azeotropic mixture by changing pressure. Azeotropic compositions if they are pressure sensitive we can change pressure and separate the components, we also call this pressure swing distillation. Now pressure swing distillation is carried out in a sequence of two distillation columns, ordinary distillation columns in both the columns one pure component is removed.

And the other component that is removed will be the azeotropic compositions corresponding to that particular pressure of the distillation column, note that in pressure swing distillation column, two columns will be operating at two different pressures, so each column will give you one pure component and one azeotropic composition corresponding to that operating pressure of the column.

Now both minimum boiling binary azeotrope and maximum boiling binary azeotrope can be separated using pressure swing distillation. Let us first consider the case of minimum boiling binary azeotrope, so the components A and B forms a binary azeotrope, consider the vapour liquid equilibrium diagram for T x y diagram first, the azeotrope is the minimum boiling azeotrope this corresponds to pressure P 1.

And this corresponds to pressure P 2 and P 1 is greater than P 2. So, note that this corresponds to higher temperature so, relatively pure B, whereas this will correspond to relatively pure A, corresponding to low temperature. Now in case of separation of minimum boiling azeotrope the feed with composition F 1 is feed to the high pressure column, column number 1. Now this column will separate this composition with feed f 1 to a bottom product which will be pure B relatively pure B.

And the overhead product or the top product will approach the isotopic composition corresponding to higher pressure. So this overhead product which approaches the high pressure azeotropic composition will be fed to the distillation column 2 operating at lower pressure, now the low pressure column that is this column number 2 will separate this feed F 2, which is an azeotropic composition corresponding to higher pressure.

This will be separated into a bottom product which is relatively pure A and a top product which will approach the azeotropic composition corresponding to low pressure. Note that this represents the bottom product and this represents the top product, look at the corresponding temperatures. So this over it from the low pressure of column will be sent to the column number 1 as recycle.

Note that this has to be pumped back you are sending the recycle from low pressure to high pressure so with this must be said pumped back, now let us consider the separation of maximum boiling binary azeotrope, so you can similarly analyze here we have the maximum boiling azeotrope so this has boiling point higher corresponding to B or A. So in this case again we make use of two distillation columns first one is operating at higher process.

And second one is operating at lower pressure feed with composition F 1 is fed to the high pressure column as usual. Now the high pressure column will separate the feed F 1 into overhead product which is relatively pure A, whereas the bottom product will approach the azeotropic composition corresponding to high pressure which will be fed to the second distillation column, which is operating at lower pressure.

The low pressure column will separate these azeotropic composition corresponding to higher pressure into overhead product D 2 which is relatively pure B and a bottom product, which will be approaching the azeotropic composition corresponding to low pressure, which will be recycled back to the high pressure column, again, this has to be pumped back.

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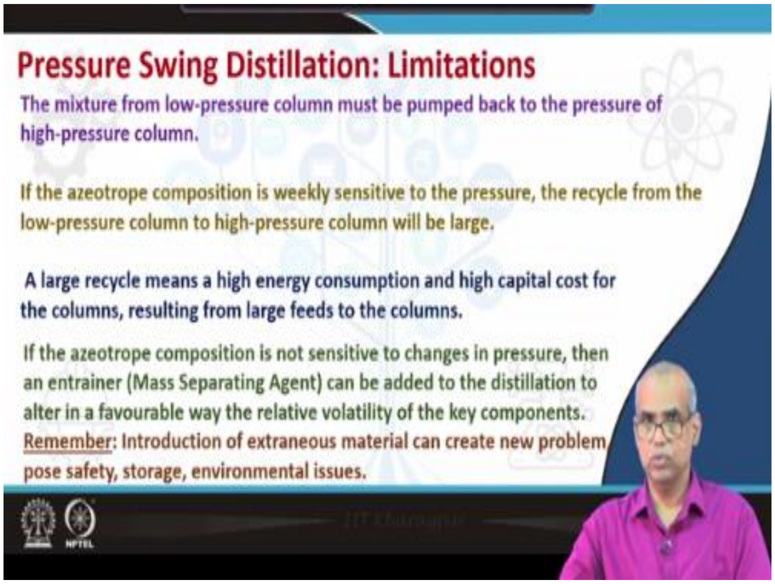

Pressure Swing Distillation: Limitations

The mixture from low-pressure column must be pumped back to the pressure of high-pressure column.

If the azeotrope composition is weekly sensitive to the pressure, the recycle from the low-pressure column to high-pressure column will be large.

A large recycle means a high energy consumption and high capital cost for the columns, resulting from large feeds to the columns.

If the azeotrope composition is not sensitive to changes in pressure, then an entrainer (Mass Separating Agent) can be added to the distillation to alter in a favourable way the relative volatility of the key components. Remember: Introduction of extraneous material can create new problem, pose safety, storage, environmental issues.

So mixture from low pressure column must be pumped back to the pressure of the high pressure column, if the azeotrope composition is not very very sensitive to pressure then the recycle from the low pressure column to the high pressure column will be large. So what is the problem if the recycle is large? A large recycle will mean high energy consumption and high capital cost for the columns resulting from large feed to the columns.

So the precision distillation column may not be economic in case the pressure sensitivity of the composition, azeotropic composition is not large. If the adjective composition is not sensitive to changes in pressure then an entrainer or mass separating agent can be added to the distillation to alter in a favorable way the relative volatility of the key components, so that will lead to either homogeneous distillation.

And homogeneous azeotropic distillation or heterogeneous azeotropic distillation on one hand where, the mass separating agent forms an azeotrope with the components one with at least one of the components present in the mixture or extractive distillation which does not see any formation of azeotrope with the internal solvent added. Now remember whenever we introduce an extraneous material there is a possibility.

That we will create new problem in separation, new problem in operation in my pose safety issues storage issues or environmental issues, so while adding a mass separating agent or entrainer we must take these into account.

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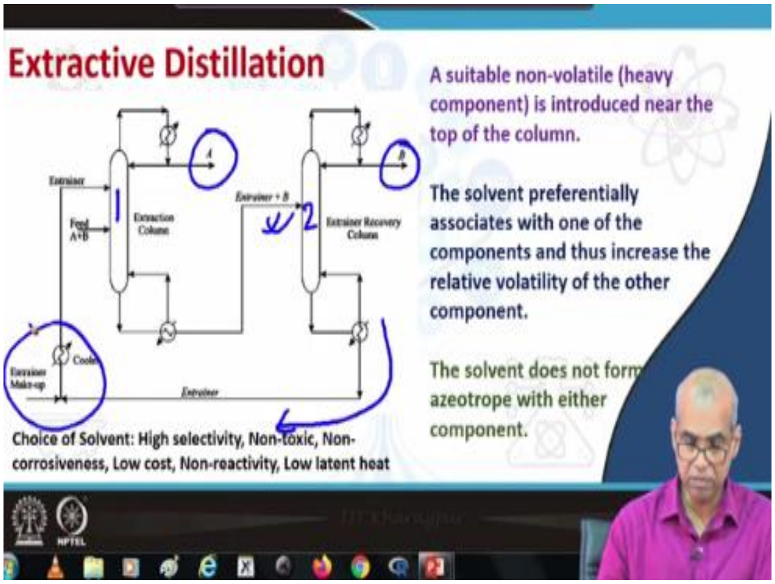

Extractive Distillation

A suitable non-volatile (heavy component) is introduced near the top of the column.

The solvent preferentially associates with one of the components and thus increase the relative volatility of the other component.

The solvent does not form azeotrope with either component.

Choice of Solvent: High selectivity, Non-toxic, Non-corrosiveness, Low cost, Non-reactivity, Low latent heat

So what you see is a schematic of extractive distillation. So extractive distillation can be of done by adding a mass separating agent. As we just discussed that when I add a mass separating agent to a azeotropic mixture the mass separating agent, which is the solvent or you also call entrainer may or may not form as azeotropes with one or two components present in the mixture, now when it form azeotropes will have cases of homogeneous azeotropic distillation or heterogeneous azeotropic distillation.

Depending on whether you have homogeneous mixture or heterogeneous mixture, if it does not form azeotropic distillation it is if it does not form azeotrope we typically call it extractive distillation in case of extractive distillation the solvent does not form any azeotrope with any of the components**.** Now let us look at the sequence of the distillation column, so it is a sequence of two columns for performing extractive distillation.

A heavy component as heavy component which is the solvent or internal is added, so is a non volatile component. So suitable non volatile heavy component is introduced and it is introduced near the top of the column the first column. Now let us consider that we have to separate mixes A and B which forms that azeotropes. Now when I add the entrainer or the solvent the solvent preferentially associates with one of these two components either with A or B.

And thereby increases the relative volatility of the other component. So it is it will be possible to take out either A or B from the overhead in the first column and as bottoms will be withdrawing. The entrainer plus the other component for this particular example B is withdrawn as over it from the first column, which you will call extraction column. And mixture of B and the integral is taken as bottoms which goes as feed to the second column which we call internal recovery column because in this column this mixture of B.

And entrainer is separated into over a B and entrainers bottom. Note that it was the heavy component, so this entrainer is feedback to the first distillation column and there will be provision for internal makeup to take care of losses etcetra. Several factors such as selectivity, toxicity corrosiveness,cost, reactivity etcetera will determine the choice of suitable solvent.

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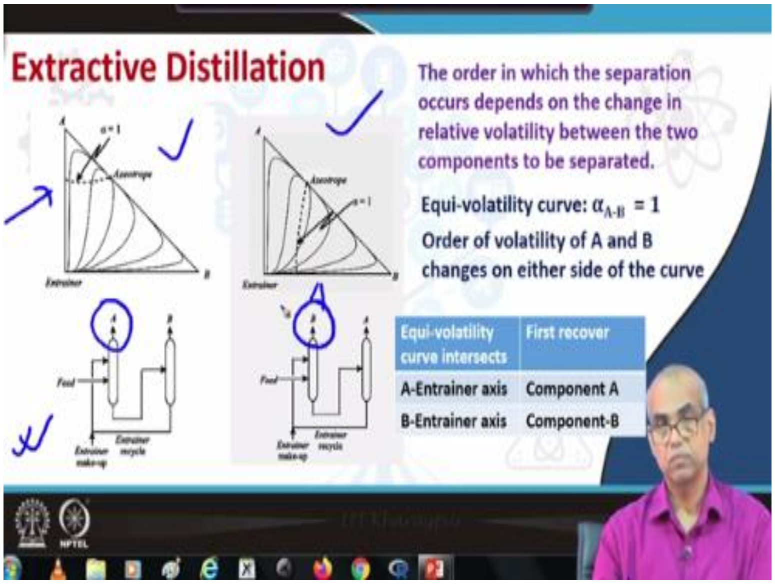

Extractive Distillation

The order in which the separation occurs depends on the change in relative volatility between the two components to be separated.

Equi-volatility curve: $\alpha_{A-B} = 1$

Order of volatility of A and B changes on either side of the curve

Equi-volatility curve intersects	First recover
A-Entrainer axis	Component A
B-Entrainer axis	Component-B

Now whether we will take out component A or component B from the first column will depend on the change in the relative volatility between the two components to be separated. When you add the solvent the solid will preference any associate with one of these two components and the relative volatility of the other component will be changed. So the order in which the separation occurs that means whether A will be separated in the first column, or B will be separated in the first column will depend on the change in the relative polarity between these two components.

Look at these diagrams, the total line represent equivalatality curve on this curve the relative volatility between component A and B is 1. The order of volatility of component A and B will change on either side of the curve, if the equivalatility curve intersects the A entrainer axis, then will first recover component A, so component A will be removed in the first column. In case the key volatility curve intercepts A entrainer axis.

And the rule also says, that if the equivalentity curve intersects B entrainer axis will remove component B first, so we will recover component B from the first column.

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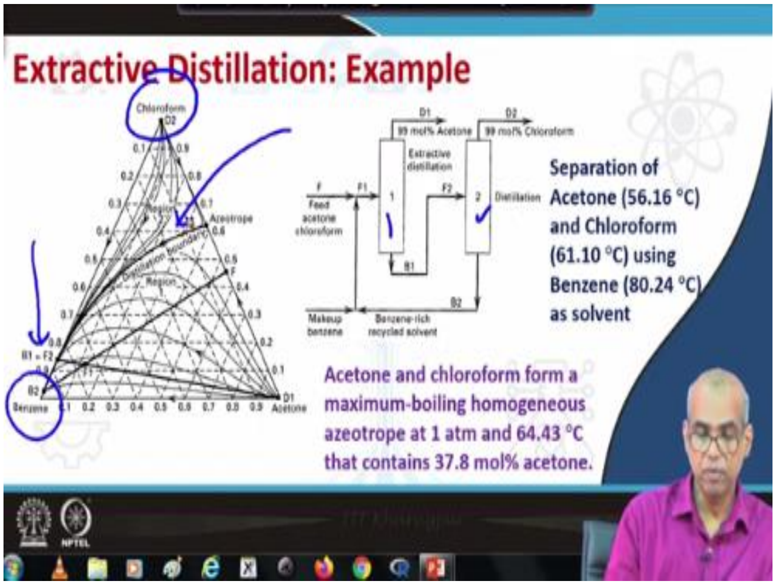

Extractive Distillation: Example

Separation of Acetone (56.16 °C) and Chloroform (61.10 °C) using Benzene (80.24 °C) as solvent

Acetone and chloroform form a maximum-boiling homogeneous azeotrope at 1 atm and 64.43 °C that contains 37.8 mol% acetone.

Let us consider another example of extractive distillation column, so this is about separation of acetone and chloroform using benzene as solvent, although use of benzene is solvent is not very encouraged this now because benzene is a carcinogenic. Acetone boils at 56.16 degrees Celsius chloroform at 61.1 degrees Celsius and benzene at 80.24 degrees. Celsius. There are normal boiling points.

Acetone and chloroforms forms a maximum boiling homogeneous azeotrope at 1 atmospheric pressures and 64.43 degrees Celsius and it contains 37.8 more percent, so is not possible to separate acetone and chloroform using ordinary discussion color, but we can separate using extractive distillation column. Let us now look at this residue combat, this represents acetone the low boiling component.

This represents chloroform the intermediate boiling components and these represent benzene, the solvent heavy component. Now the feed which is a mixture of acetone and chloroform enters the column 1, but before entering it also mixes with the recycle which is bottoms of column 2, which is basically recovered benzene recycled benzene. So, when this recycle benzene stream mixes with the feed stream of acetone and chloroform the resulting stream let us call F1.

So F1 is obtained by joining this feed and the recycle benzene stream, note the location of B 2, it is not exactly on the vertices because it is not pure 100% benzene, it is recycled. So this F 1 enters column, number 1. Now look at the material balance line that joining D 1, F 1 and B 1 point D 1, B 1, F 1 are collinear lying on the material balance line also the acetone and this B 1 point around the same residue curve.

So, this is a feasible split, so this possible for me to obtain the D 1 the lowest boiling component as over it in the first column and the B 1, which is a mixture of chloroform and benzene as bottom. Now this mixture of chloroform and benzene can be separated in column 2 as chloroform over it and benzene bottoms benzene will be recycled to the column number 1. So, this is how you can explain with the help of a residue come map.

The feasibility of the sequence for this separation of isotropic mixture through distillation through isotropic distillation. Note that this represents a distillation boundary 7 in the presence of distillation boundary by addition of this vengeance solvent it was possible to separate chloroform and acetone.

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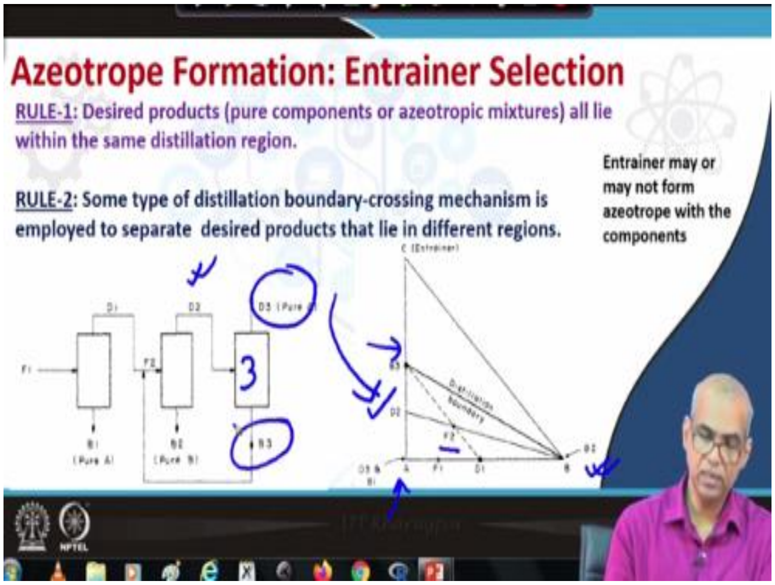

Azeotrope Formation: Entrainer Selection

RULE-1: Desired products (pure components or azeotropic mixtures) all lie within the same distillation region.

RULE-2: Some type of distillation boundary-crossing mechanism is employed to separate desired products that lie in different regions.

Entrainer may or may not form azeotrope with the components

Now let us consider the case where the added solvent or entrainer form azeotropes. How do I select entrainer? Let us talk about two rules, rule 1 Select entrainer such that the desired product. lie within the same distillation region. So if you consider the residue come back then we should select an entrainer such that the desired products all lie within the same distillation region, the desired products means the pure components as well as azeotropic mixtures.

Rule 2 select entrainer such that some type of distillation boundary crossing mechanism is employed to separate desired products that lie in different regions, so if desired products are lying in different regions some type of distillation boundary crossing mechanism is employed. Let us take again one example we have a mixture of A and B which forms a binary azeotrope represented by D 1, so I add entrainer C.

Entrainer C form binary azeotrope with a indicated by B 3. Now let us find out a feasible sequence for the separation. The feed mixture which is a binary mixture F 1 is splitted into pure A as bottom and this binary azeotrope D 1 as over it. Note that this D 1 is a minimum boiling azeotrope that has been formed between A and B. So this goes as over head and we get pure A as bottoms in the first column.

So this azeotrope goes to column number 2 as feed, but before that it also mixes with the recycle stream coming from column number 3 which will be 3, another azeotropic mixture which is basically azeotropic composition mixture of A and C the entrance is C. So the D 1 and B 3 is mixed, so the resulting stream that is entering column number two is represented by F 2. Note that all are lying below these distillation boundaries.

So, all are lying in one distillation region. Consider the material balance line B F 2 and D 2, So the column number two will separate the mixture F 2 into D 2 and this B are represented by B 2 pure B. So now the binary mixture D2 which is a binary mixture of entrainer and A will go to column 3 which will be splitted into B 3 bottom azeotropic mixture and A pure as over it. And the B 3 azeotropic composition of a and entrainer C will be recycled to column 2, So this way you can analyze the feasibility of the sequence.

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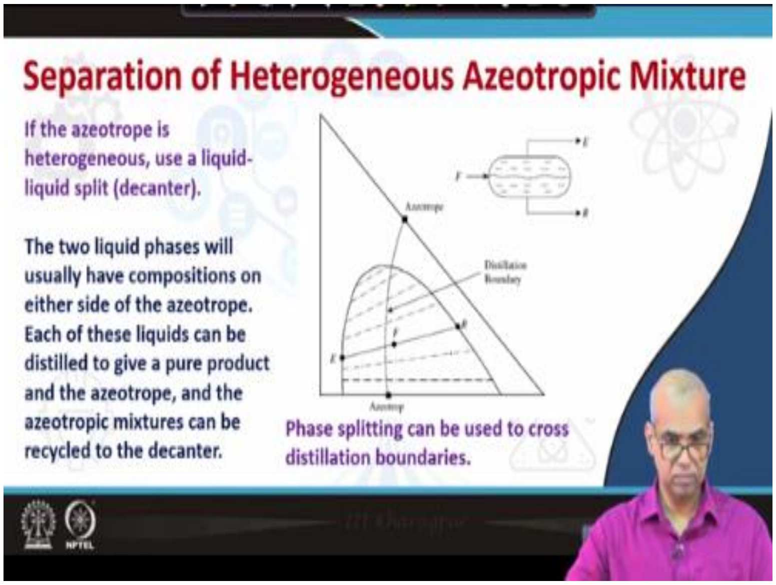

Separation of Heterogeneous Azeotropic Mixture

If the azeotrope is heterogeneous, use a liquid-liquid split (decanter).

The two liquid phases will usually have compositions on either side of the azeotrope. Each of these liquids can be distilled to give a pure product and the azeotrope, and the azeotropic mixtures can be recycled to the decanter.

Phase splitting can be used to cross distillation boundaries.

This is the description that we just discussed, separation of heterogeneous azeotropic mixture. If the azeotropic heterogeneous we can use a liquid-liquid split by decanter the two liquid phases will usually have compositions on either side of the azeotrope. Each of these liquids can be distilled to give a pure product and the azeotrope and mixtures can be recycled back to the decanter, note that the liquid splitting can be used to cross the distillation boundary. So this is an advantageous point about heterogeneous azeotropic separation.

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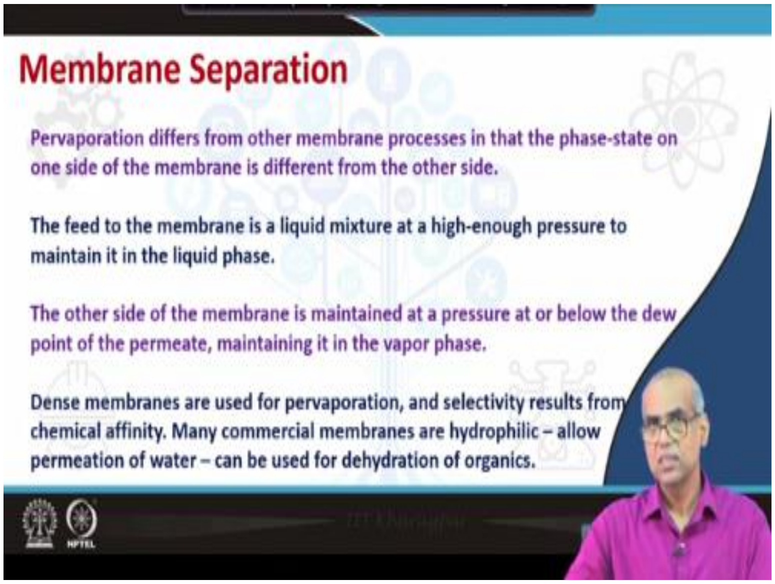

Membrane Separation

Pervaporation differs from other membrane processes in that the phase-state on one side of the membrane is different from the other side.

The feed to the membrane is a liquid mixture at a high-enough pressure to maintain it in the liquid phase.

The other side of the membrane is maintained at a pressure at or below the dew point of the permeate, maintaining it in the vapor phase.

Dense membranes are used for pervaporation, and selectivity results from chemical affinity. Many commercial membranes are hydrophilic – allow permeation of water – can be used for dehydration of organics.

Finally, we will talk about membrane process of azeotropic mixture membrane modules can be used in conjunction with the distillation column to separate isotopic mixture pervaporation differs from other membrane processes in that the phase state on one side of the membrane is different from the other side. The feed to the membrane is the liquid mixture at a high enough pressure to maintain it in the liquid phase.

The other side of the membrane is maintained at a pressure at or below the dew point of the permeate, thereby it is maintained in the vapour phase. Dense membranes are used for pervaporation and selectivity results from chemical affinity. Many commercial membranes are hydrophilic in nature, so they preferentially allow permeation of water. So it is obvious that hydrophilic membranes can be used for dehydration of organics such as the separation of alcohol and water dehydration of ethyl alcohol separation of isopropanol and water etcetera.

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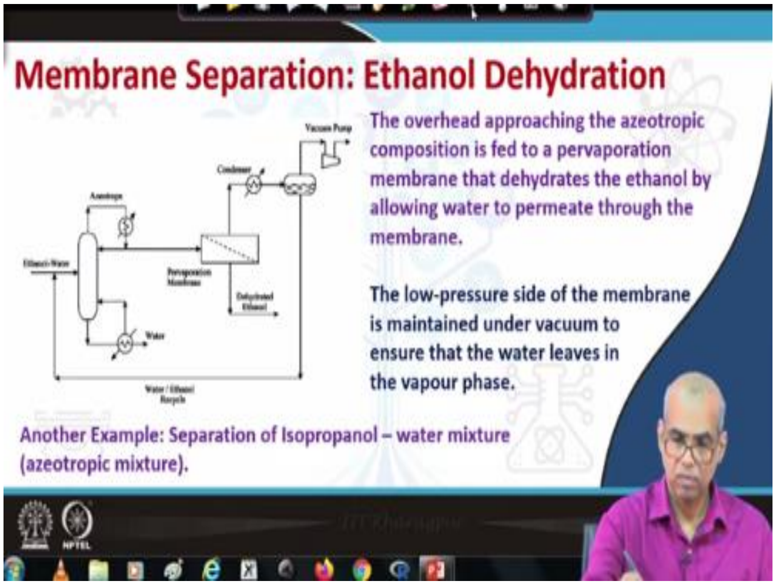

Membrane Separation: Ethanol Dehydration

The overhead approaching the azeotropic composition is fed to a pervaporation membrane that dehydrates the ethanol by allowing water to permeate through the membrane.

The low-pressure side of the membrane is maintained under vacuum to ensure that the water leaves in the vapour phase.

Another Example: Separation of Isopropanol – water mixture (azeotropic mixture).

So in this schematic, let us consider the flow sheet for the ethanol dehydration using membranes, so look at this first distillation column where ethanol water mixture enters feed. So the overhead product will approach that azeotropic composition of water and ethanol from the bottom of the first column, we will get relatively pure water. Now this overhead azeotropic composition is fed to a pervaporation membrane that membrane will dehydrate the ethanol by allowing the water to permeate through it.

So it can alter the vapour liquid equilibrium, it will permeate the water to pass through it. So dehydrated ethanol will come out from one side and the water will be permeated from the low pressure side, which is maintained under vacuum to ensure that water leaves in the vapour phase.

So after condensing the water ethanol recycle stream can be fed back to the column 1 because this stream may still continue significant amount of ethanol.

So this is how a membrane will be used in conjunction with a distillation column for separation of azeotropic mixture.

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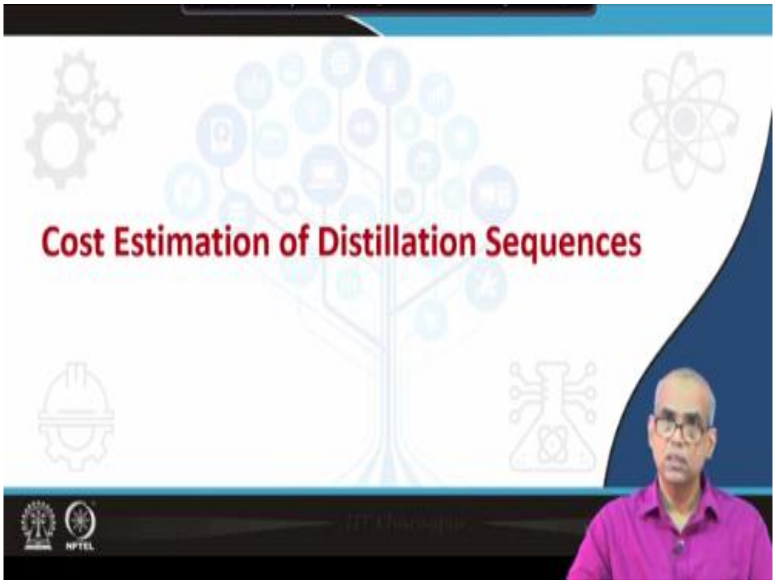

Cost Estimation of Distillation Sequences

Now let us look at the cost estimation of distillation sequences which basically requires cost estimation of distillation columns. Note that we can find out the cost of distillation sequences simply by adding the cost of individual distillation columns.

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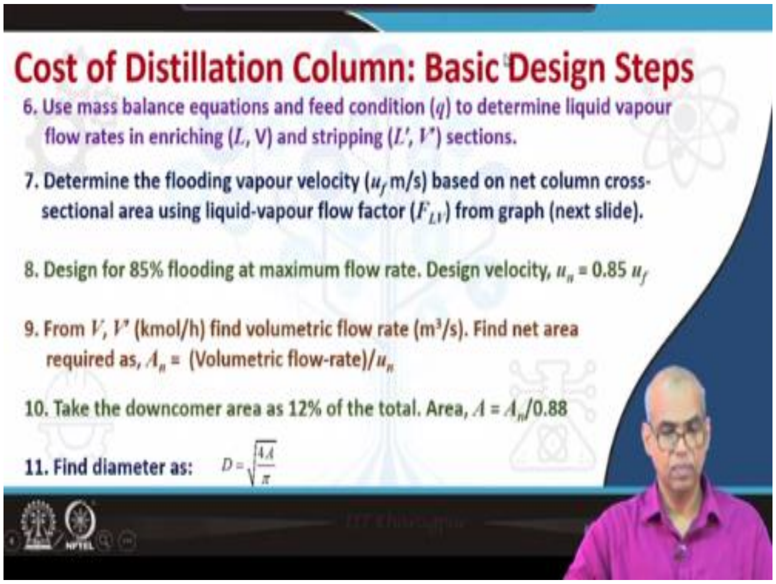

Cost of Distillation Column: Basic Design Steps

6. Use mass balance equations and feed condition (q) to determine liquid vapour flow rates in enriching (L, V) and stripping (L', V') sections.
7. Determine the flooding vapour velocity (u_f m/s) based on net column cross-sectional area using liquid-vapour flow factor (F_{LV}) from graph (next slide).
8. Design for 85% flooding at maximum flow rate. Design velocity, $u_n = 0.85\ u_f$
9. From V, V' (kmol/h) find volumetric flow rate (m^3/s). Find net area required as, $A_n =$ (Volumetric flow-rate)/u_n
10. Take the downcomer area as 12% of the total. Area, $A = A_n/0.88$
11. Find diameter as: $D = \sqrt{\frac{4A}{\pi}}$

Now for estimation of the cost of a distillation column we need to know the details of the distillation columns such as the diameter of the column, height of the column, the number of trees in the column, the reboiler heat load, the condenser heat load, etc. So there will be fixed cause associated there will also be operating cost associated. So the distillation, so the cost of the sale cost of the trays etc will give me the fixed cost for the shell.

Or the tower you will then the cost of the reboiler, the cost of the condenser, he cost of cooling utility the cost of steam utility will give me the operating cost. Now, let us first quickly go through the basic design steps of a distillation column, first define light and heavy key components find the relative volatility of the key components.

Calculate the relative volatility of the light key with respect to the heavy key then we have discussed Fenske equation you use transcript equation to find minimum number of plates using specified splitting of key components, use Underwood equation to find minimum reflux, use Gilliland correlation to find actual number of plates, typically you can find finite reflexes 1.2 to 1.3 times of the minimum reflux that you have found out using Underwood equation.

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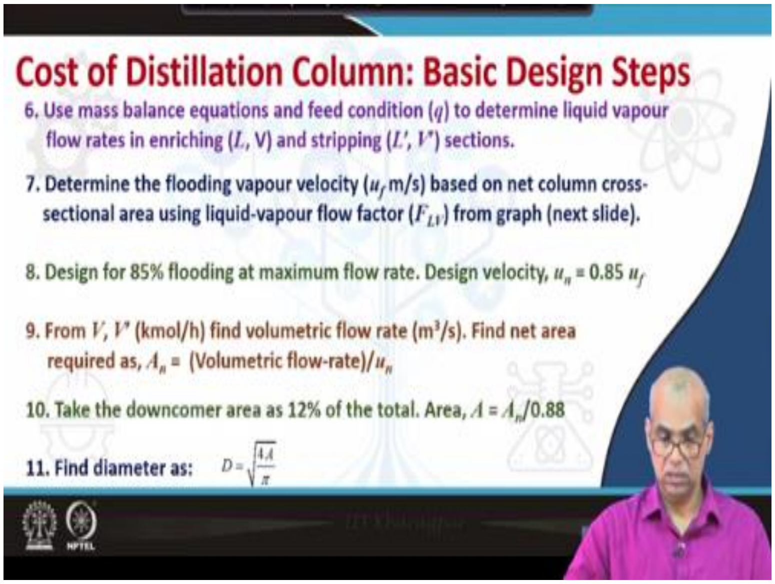

Cost of Distillation Column: Basic Design Steps

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11. Find diameter as: $D = \sqrt{\frac{4A}{\pi}}$

Use mass balance equations and feed condition to determine liquid vapour flow rates in the enriching section as well as in the stripping sections, you determine the flooding velocity you determine the flooding vapour velocity based on net column cross sectional area using liquid vapour flow factor.

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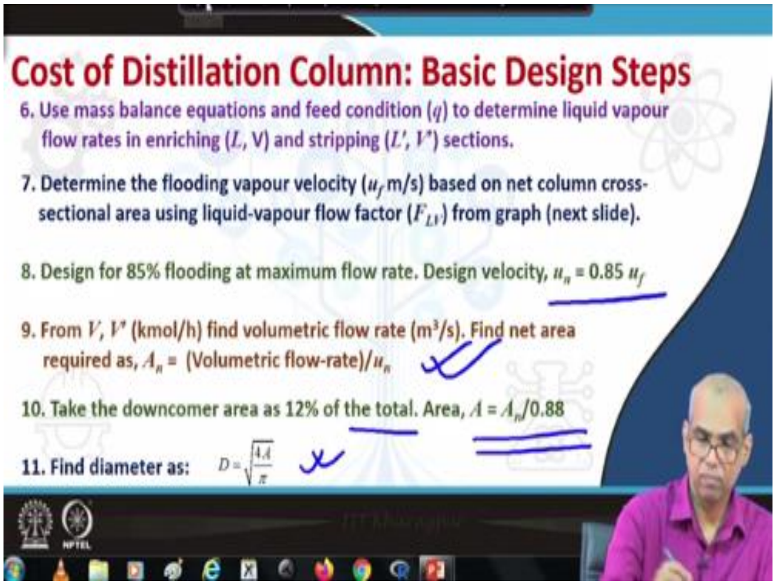

Cost of Distillation Column: Basic Design Steps

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So this is the graph, which gives you a relationship between K 1, which is defined like this with the Factor F L V which is defined like this. So determine the flooding vapour velocity you have based on the net column cross sectional area using liquid vapour flow factor from the graph. Design for 85% flooding at maximum flow rate, so the design velocity will be 0.85 of the flooding vapor velocity UF.

We have found out the vapour flow rates by material balance may be those are in kilo mole per hour, so you find volumetric flow rate in terms of meter cube per second or meter cube per hour. Then finite area required as volumetric flow rate divided by the design vapour velocity, consider the downcomer area as 12% of the total area. So the area will be this area divided by 0.88. So once you have found out the area required you find out the diameter as D equal to square root of 4 A by pi. So this is how we will be able to find out the diameter;

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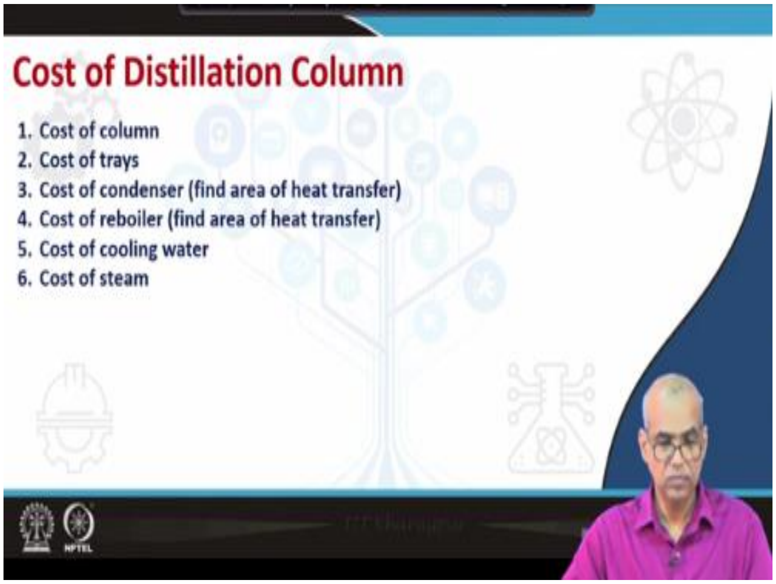

Cost of Distillation Column

1. Cost of column
2. Cost of trays
3. Cost of condenser (find area of heat transfer)
4. Cost of reboiler (find area of heat transfer)
5. Cost of cooling water
6. Cost of steam

We know the number of trays, so we will find out the height of the distillation column, typically the tray spacing is considered as two feet then you have to consider a space vapour space at the top of the discussion column and a liquid space at the bottom of the distillation column. So there has to be liquid old up over there is required for the reboiler, so once we have this information's we can find out the cost of a distillation column provided.

I know the cost of column cost of trace cost of condenser which can be obtained from the area required for the heat transfer cost of re boiler again area required for the heat transfer. So the manufacturer or vendor can supply us the cost of columns with this height or cost per column with these many trays etcetera, for cost of condenser reboiler for such area then from the knowledge of cooling water cost and cost of the steam will be able to find out the cost of distillation column.

Fixed cost as well as operating cost may be on the annual basis as well, note that you also have to find out the reboiler heat load condenser heat load by doing energy balance equations, so once you have this information, it can it is possible to find out the cost of distillation columns.

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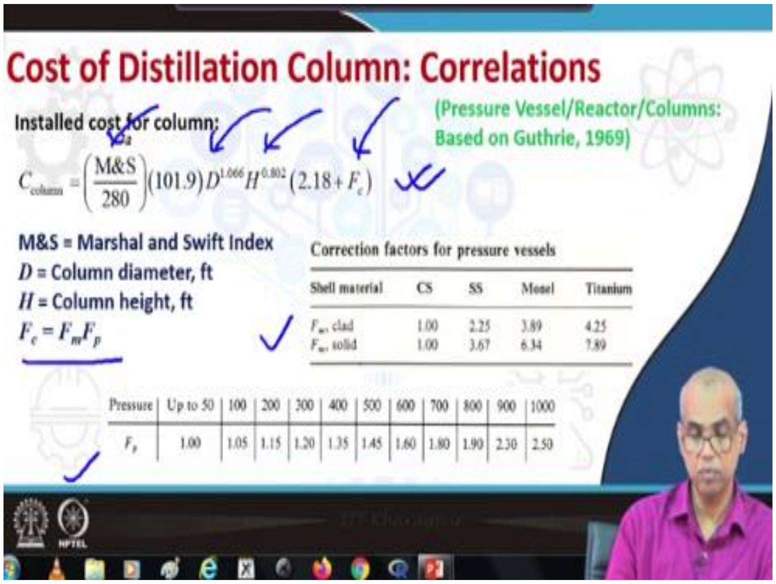

Cost of Distillation Column: Correlations

Installed cost for column:

(Pressure Vessel/Reactor/Columns: Based on Guthrie, 1969)

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

M&S = Marshal and Swift Index

D = Column diameter, ft

H = Column height, ft

$F_c = F_m F_p$

Correction factors for pressure vessels

Shell material	CS	SS	Monel	Titanium
F_m, clad	1.00	2.25	3.89	4.25
F_m, solid	1.00	3.67	6.34	7.89

Pressure	Up to 50	100	200	300	400	500	600	700	800	900	1000
F_p	1.00	1.05	1.15	1.20	1.35	1.45	1.60	1.80	1.90	2.30	2.50

But frequently will be using several correlations that are available in the literature if we have all the cost data directly from the vendor, so that will be very recent data and that will be very useful but in absence of such information's we can find out the cost of distillation column make by making use of several correlations. One of the correlations as given by Douglas is based on Guthrie which was proposed in 1969, so this is quite outdated.

So even if you use the cost indexes which takes care of inflation and update the data, this will not be quite appropriate because the updating is ok within obtaining or so beyond that the use of the cost indexes to update old data may not give satisfactory results anyway, but lotus look at a correlations install cost of column is given by this correlation, which is a function of diameter of the column, height of the column and a correction factor FC, which is depended on FM and FP which can be obtained from these two tables.

Here M and S represent martial and swift index, so the current martial and swift index you have to put over there, but I told you that you have to make we have to take caution because it is quite old.

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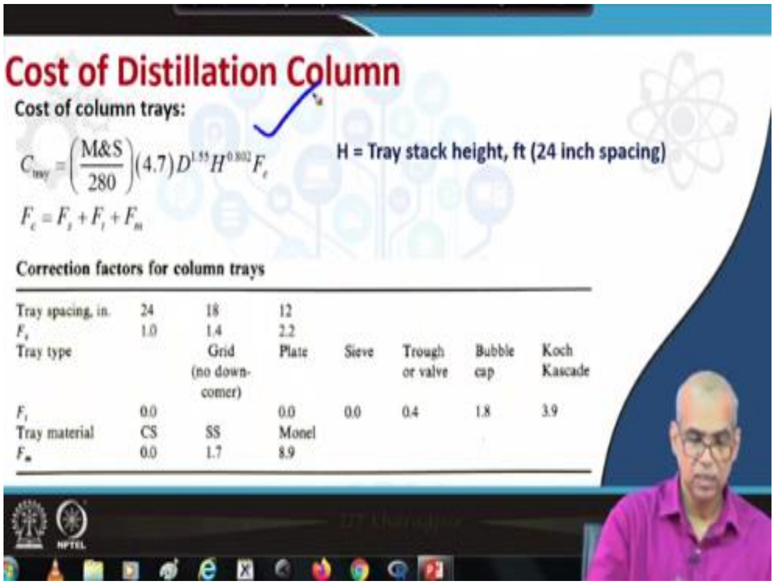

Cost of Distillation Column

Cost of column trays:

$$C_{tray} = \left(\frac{M\&S}{280}\right)(4.7)D^{1.55}H^{0.802}F_c$$

$$F_c = F_s + F_t + F_m$$

H = Tray stack height, ft (24 inch spacing)

Correction factors for column trays

Tray spacing, in.	24	18	12				
F_s	1.0	1.4	2.2				
Tray type		Grid (no down-comer)	Plate	Sieve	Trough or valve	Bubble cap	Koch Kascade
F_t	0.0		0.0	0.0	0.4	1.8	3.9
Tray material	CS	SS	Monel				
F_m	0.0	1.7	8.9				

So cost of column trays similarly can be obtained the correction factor as components FS, FT, FM, which can be obtained from this table.

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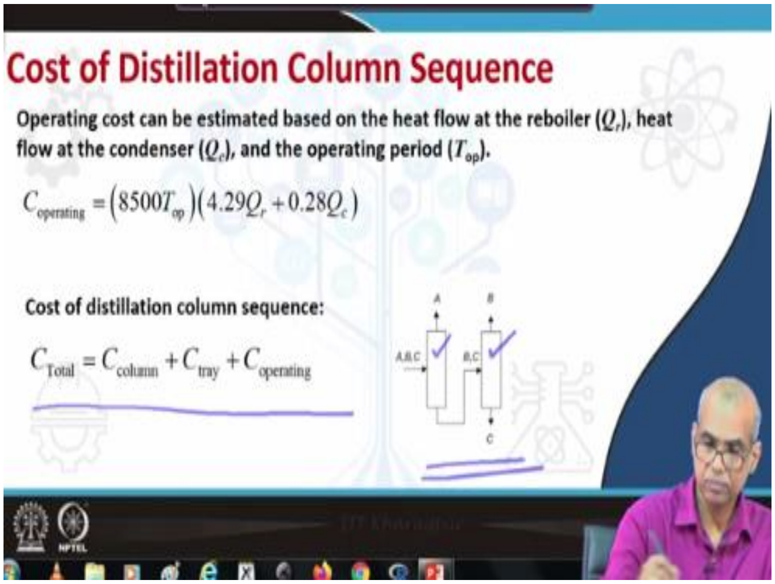

Cost of Distillation Column Sequence

Operating cost can be estimated based on the heat flow at the reboiler (Q_r), heat flow at the condenser (Q_c), and the operating period (T_{op}).

$$C_{operating} = (8500T_{op})(4.29Q_r + 0.28Q_c)$$

Cost of distillation column sequence:

$$C_{Total} = C_{column} + C_{tray} + C_{operating}$$

Then the operating cost can be estimated based on the heat flow at the reboiler and the heat flow at the condenser and the operating period speed of operation. So there is can be obtained using this correlation, so once you have this cost of column, cost of tray and cost of operation, coming from the reboiler and the condenser you can find out the total cost. So if you have this sequence, so you find out the cost for this column cost of second column we can add up.

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Cost of Distillation Column: Software

ASPEN Capital Cost Estimator (Estimation of CAPEX, OPEX) : Commercial

DWSIM : Open source

CAPCOST : Turton et al.

Download capcost_2017.xlsm from:

https://richardturton.faculty.wvu.edu/publications/analysis-synthesis-and-design-of-chemical-processes-5th-edition

Now, there are other correlations also in the later ratio, there are also several softwares which will do the cost estimation for us of course Aspen capital cost estimator is a very reliable tool for doing cost estimation, it will do both estimation of capital cost and estimation of operating cost is a commercial software. DWSIM is a free; software open source software, which also will be able to do the cost estimation.

CAPCOST is a basically a spreadsheet tool like an Excel say which is written by the author of this book analysis synthesis and design of chemical process Turton, and can be downloaded from the website from this book, which is given here. So cap cost is very simple and easy to use, and has quite detailed functionality for cost estimation you can estimate cost for different equipment and there are other functionalities.

I suggest that you download this software and see for yourself that how this can be used for estimation, of course of various equipment.

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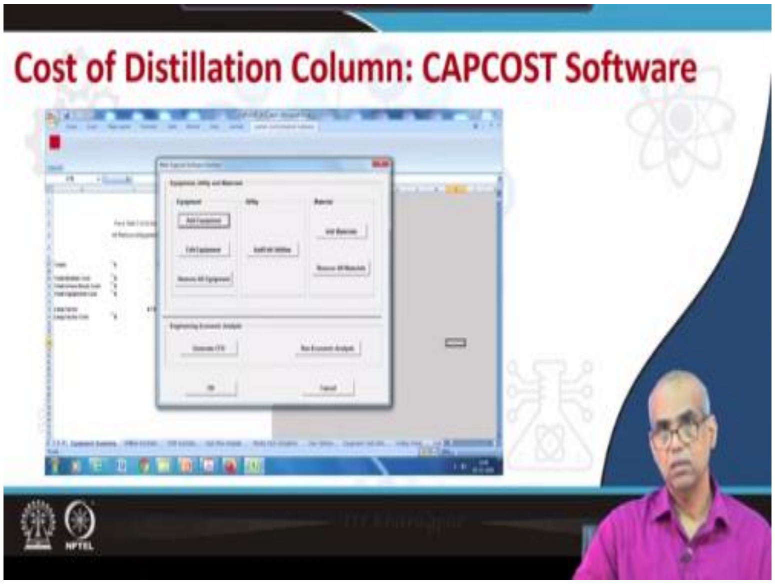

Cost of Distillation Column: CAPCOST Software

So, It is very easy so if you download it and run the macro you will you will see such schemes add equipment edit equipment etcetera.

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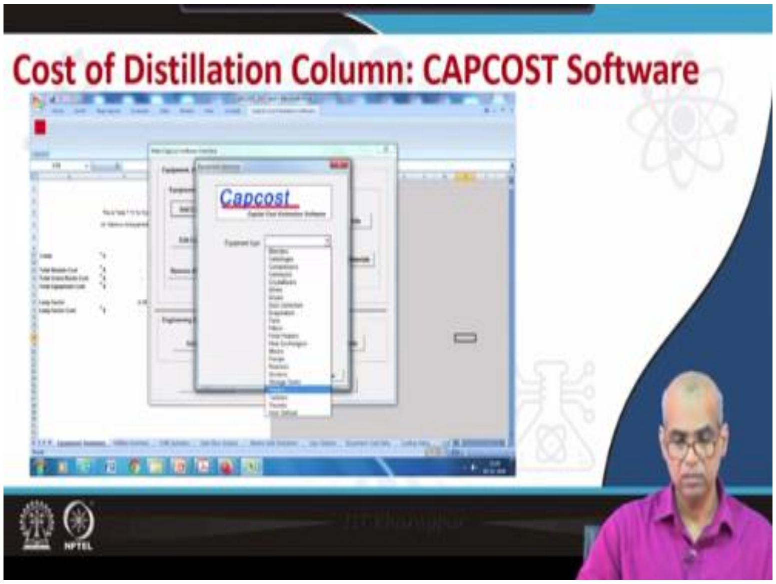

Cost of Distillation Column: CAPCOST Software

You click on add equipment, so you will get a list of all the equipments that are available and you can do the cost estimation for.

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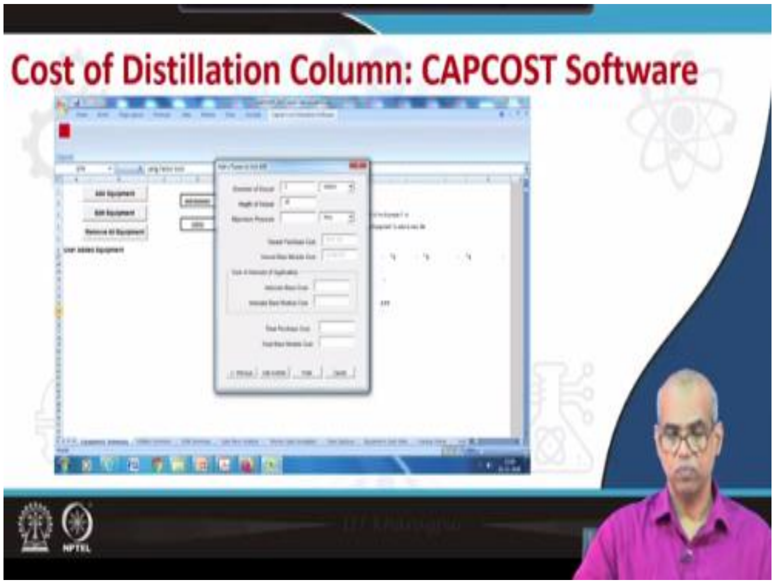

Cost of Distillation Column: CAPCOST Software

So, let us say I select hour and then it will ask for entries such as diameter of a shell, height of vessel, material up construction etcetera, and then it will do the cost estimation for you.

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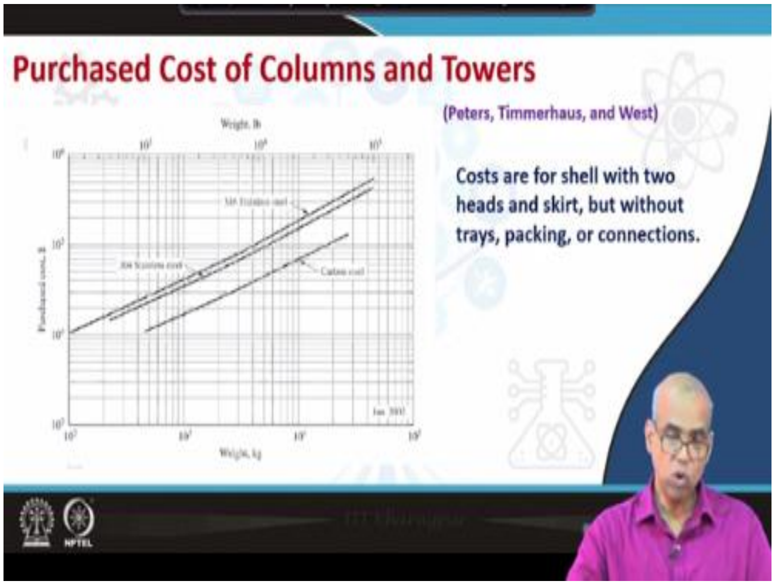

Purchased Cost of Columns and Towers

(Peters, Timmerhaus, and West)

Costs are for shell with two heads and skirt, but without trays, packing, or connections.

There are also other cost data; let us say purchase cost of columns and towers as available in the Peter, Timmerhaus and West book. So these are purchase cost weight versus purchase cost, cost are for sale with two heads and skirt but, without trays, packing, or connections. So how the cost data purchase cost data changes with weight of columns and towers for various material of construction, such as carbon steel, stainless steel.

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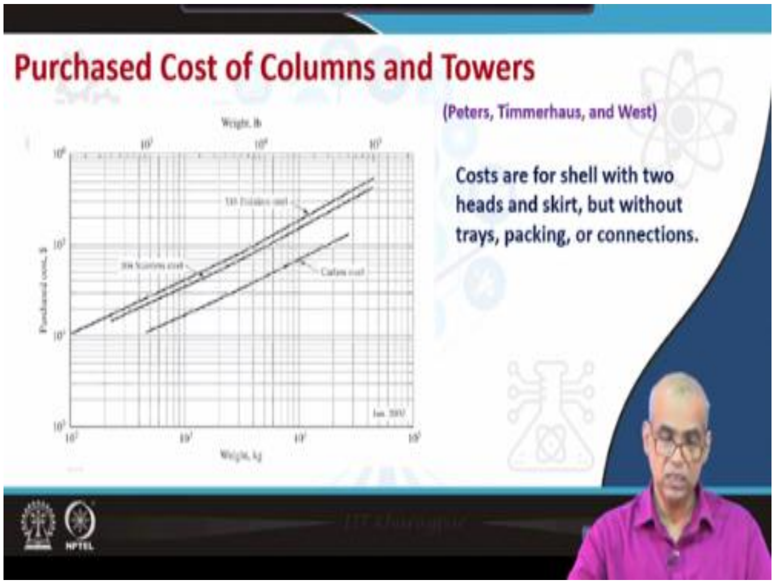

Purchased Cost of Columns and Towers

(Peters, Timmerhaus, and West)

Costs are for shell with two heads and skirt, but without trays, packing, or connections.

This is purchase cost of vertical columns price does not include trays packing or connections.

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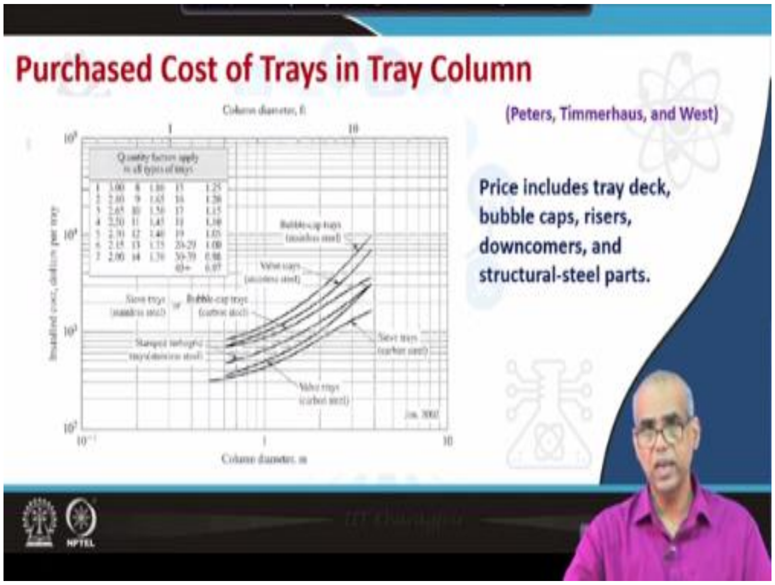

Purchased Cost of Trays in Tray Column

(Peters, Timmerhaus, and West)

Price includes tray deck, bubble caps, risers, downcomers, and structural-steel parts.

This is install cost for steel column connections and this is virtuous cost of trays in tray column for various types of trays bubble cap trays, ball trays etcetera, price includes tray desk, bubble, caps, risers, downcomers and structural steel parts. So we can use such graphical correlations, we can use equations that are available one set of equations we have seen but there are several other such correlations available in the literature.

And these days the cost estimations are generally done more reliably by making use of softwares. And I suggest that you at least use cap cost to get a feeling of how this cost estimation can be done, with this we conclude our discussion of lecture or module 9.