

Thermal Operations In Food Process Engineering: Theory And Applications
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Lecture – 58
Distillation (Contd.)

Good morning. We have been discussing on Distillation right and the as you said distillation is a big unit we may need some classes. So, today in 20 sorry, in 58th lecture on distillation, let us look into some more aspects of distillation because basically this is made of this is from McCabe–Thiele method by enlarge, right.

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- hotter vapour - **transfers heat**
- liquid - receives heat
- vapour **condenses to liquid**
- condensate - **richer** in the **less volatile components**
- **heat input from the vapour - more liquid boils off**
- liquid - on boiling - **generating more vapour**
- next tray - **richer more volatile components**
- **separation**
- **low boiling point components**
- **higher boiling**

The diagram illustrates a distillation tray. It shows a cross-section of the tray with an 'ACTIVE TRAY AREA' where vapour is rising. An 'OUTLET WEIR' is shown on the right side, through which vapour passes. A 'DOWNCOMER' is shown on the right side, where liquid flows down. Labels include 'VAPOUR', 'LIQUID', 'OUTLET WEIR', and 'DOWNCOMER'.

So, here you see we have given a graph or we have given one diagram. There we have said that you see in the previous class we were discussing with different types of caps. So, bubble cap was one of (Refer Time: 01:28), right.

Different in the trays, different vapour liquid when they are coming across so that interaction is being done in the different these are called different plates or sieves or whatever we call it right. So, there we are putting on stage that is also one tray also. So, there we said that there is outer weir through which the vapour they go up like this and the liquid that comes down, right. So, like that this is also outlet weir right.

So, if these be the active tray, then this perhaps we may follow for some time because from the revallet down below these vapours are coming from the revallet down below these vapours are coming and crossing the different layers different trays right. And while it is doing so, the liquids which are coming they are in contact with this vapours so, heat is getting exchanged right.

So, what happens hotter vapour they transfer heat because they are at higher temperature and we know from higher to lower temperature it is being transferred and liquid that receives the heat right and by this process when the vapour is transferring heat to the liquid some vapour is forming also liquid. So, the liquid which actually is coming down if it would have been L now it is $f L + \text{a little } \Delta L$ right whereas, the vapour which got evaporated because of the transfer of the heat with the liquid right because liquid is at the higher temperature. So, liquid has given the heat to the vapour rather a liquid has received some heat. So, that is vaporizing. So, that vapour is now going out.

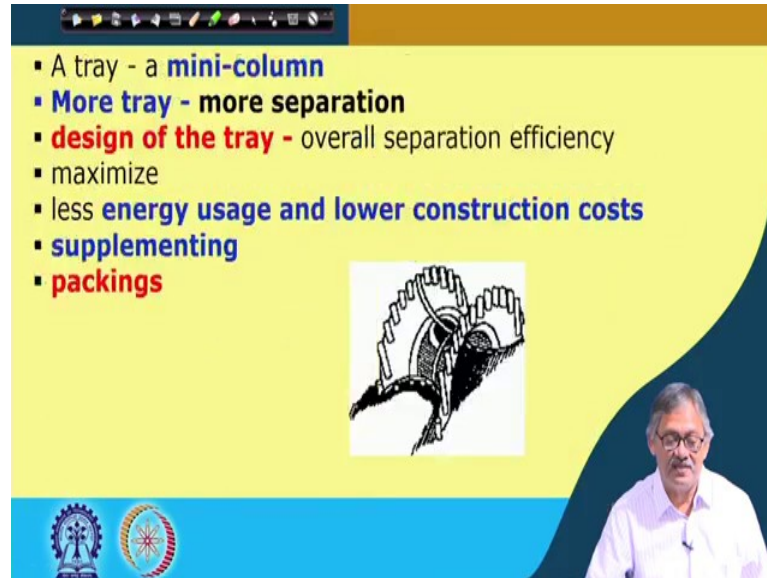
So, both liquid and vapour they are under heat transfer right. Some vapour condenses to liquid that we just said and the condensate then becomes richer in the less volatile components. Now, condenser means the liquid which is coming out right. So, what is happening we earlier we said if it is a binary mixer A and B right and if A is more volatile and B is less volatile that volatility also we discussed right, may be some more we will be discussing. So, that if A becomes more volatile and B is less volatile then when the vapour is going and it is condensing back to liquid; so, it is the less volatile component is more in the liquid that the more volatile because more volatile has already gone into the vapour, right.

So, it becomes richer in less volatile component right and that is the condensate is a less volatile components and heat input from the vapour is more liquid boils off and that liquid which on boiling generate more vapour and that goes to the next tray and that tray it is richer in more volatile components, right. So, more volatile is going from the lower to the higher trays and less volatile component is coming back from the higher to the lower trays, right.





So, and by that process separation takes place and low boiling components they are low boiling components, they are getting separated and there is higher boiling component both. Low boiling is coming to the low boiling means boiling point is low so, that means,

that is more volatile so, that is going up and less volatile or higher boiling that is going down right. So, this way the trays are under heat transfer, right.

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- A tray - a **mini-column**
- **More tray - more separation**
- **design of the tray** - overall separation efficiency
- maximize
- less **energy usage and lower construction costs**
- **supplementing**
- **packings**

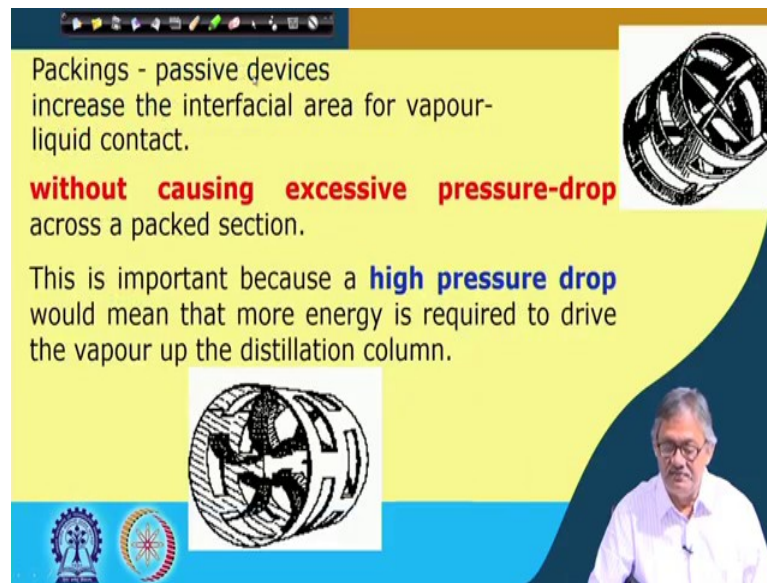


And, there can be some more effectiveness of the heat trays can be increased by saying that a tray is like a mini-column because in the whole column what you are doing number of trays you have; in all the trays there is a change of heat and exchange of the mass also. And in that process more volatile is going up less volatile is going down, right.

So, that means, and that is happening in each of the trays this tray this tray this tray each of the trays it is happening. So, if it is happening in each of the trays then we can call each of the trays because collectively also that is doing. So, each of the tray is like a mini-column right where; that means, more number of trays more separation, less number of trays less separation that is obvious.

And, if we see the design of the tray where overall separation efficiency is also a factor and, that can be maximized with less energy usage and lower construction cost and supplementing with the packaging materials like this. These are the packaging materials which helps to exchange the heat or exchange the more volatile and less volatile right, and these we can see in other this is one type.

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Packings - passive devices increase the interfacial area for vapour-liquid contact.

without causing excessive pressure-drop across a packed section.

This is important because a **high pressure drop** would mean that more energy is required to drive the vapour up the distillation column.

The slide features a 3D rendering of a spherical packing material with a complex internal structure. In the bottom right corner, there is a small inset photograph of a man with glasses and a white shirt. The footer contains logos of various institutions, including one with a gear and a figure, and another with a circular emblem.

Other two types are like that packing materials right. So, that is the passive device which increases the interfacial area for vapour liquid contact like in our heat transfer also we had increased the surface area by putting pins. So, here also by putting these kind of packing material, you are increasing the interfacial surface area and thereby increasing the vapour liquid contact, right.

So, without causing excessive pressure drop, that is again a fundamental thing because you have so many trays in the columns. So, vapours are going up and liquids are of course, are coming down; liquid coming down may be assisted by the gravity if it is a vertical column there are many types if it is a vertical column then that is assisted by the gravity.

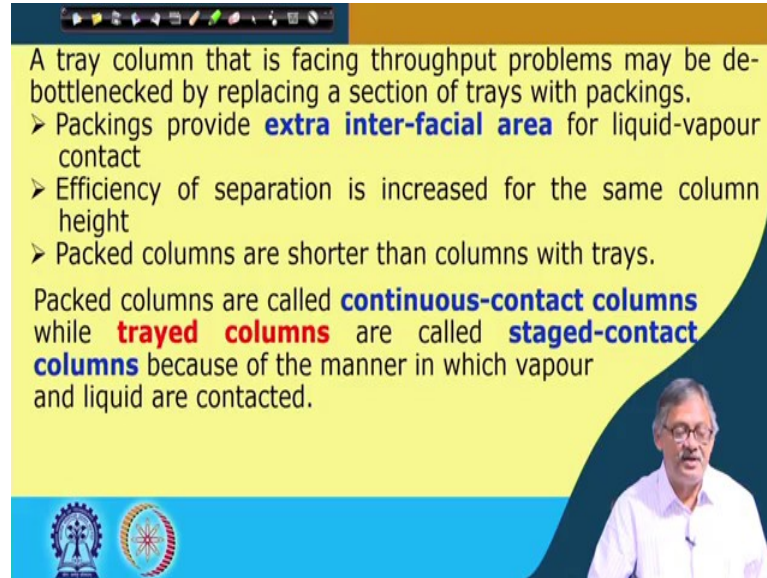
But, the thing is that while doing so, if while we are increasing the a passive in increasing the heat exchange of heat or mass with the vapour and liquid both and there we are introducing this kind of packings, we have to also keep in mind that there should not do or cause any pressure drop, right.

It is not possible that any pressure drop that should not cause pressure drop which is beyond the; I mean, beyond the acceptable limit such that if there is a so much pressure drop then you have to make by sum means that vapour has to go up, right. So, it cannot be that pressure drop will be high by introducing that this kind of packing and then you

will be in trouble. So, packing will assist interfacial area increment, but pressure drop has to be minimum.

This is important because a high pressure drop would mean that more energy is required to drive the vapour up to the distillation upper side or that is in separation columns, right.

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A tray column that is facing throughput problems may be de-bottlenecked by replacing a section of trays with packings.

- Packings provide **extra inter-facial area** for liquid-vapour contact
- Efficiency of separation is increased for the same column height
- Packed columns are shorter than columns with trays.

Packed columns are called **continuous-contact columns** while **trayed columns** are called **staged-contact columns** because of the manner in which vapour and liquid are contacted.

So, if that be true, then let us look into this part that a tray column that is facing throughput problems may be de-bottlenecked by placing a section of trays with packings; if there is a separation problem this may add up this separation technique, right.

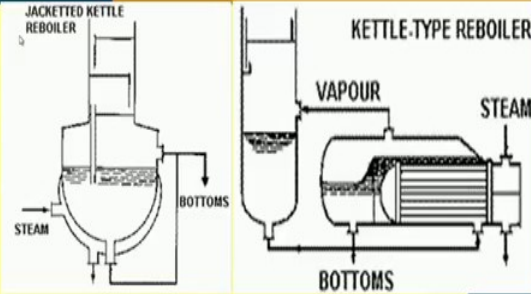
Packing provides extra inter facial area which you have already said for liquid and vapour to interact. And, efficiency of separation is increased for the same column height right; without increasing the height of the column we can increase the efficiency of these plates by introducing these packing materials, right.

So, packed columns are shorter than columns with trays; obviously, because you were increasing more interfacial area or more service area to interact with the vapour and liquid. Packed columns are called continuous-contact columns while trayed columns are called staged-contact columns because of the manner in which the vapour and liquid are contacted, right.

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There are a number of designs of **reboilers**. They can be regarded as heat-exchangers that are required to transfer enough energy to bring the liquid at the bottom of the column to **boiling point**.

volatility



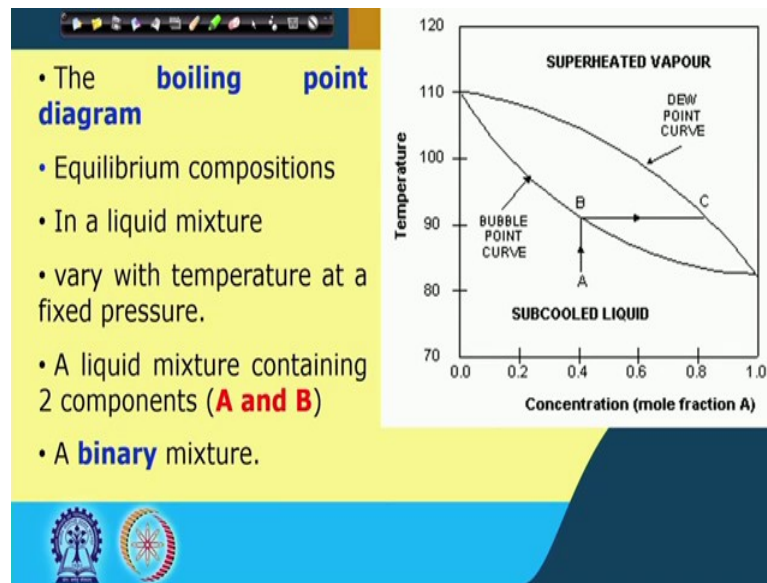
The image contains two technical diagrams of reboilers. The left diagram, titled 'JACKETED KETTLE REBOILER', shows a cylindrical vessel with a jacket around it. A 'STEAM' inlet is on the left, and a 'BOTTOMS' outlet is on the right. The right diagram, titled 'KETTLE-TYPE REBOILER', shows a similar vessel but with a 'VAPOUR' outlet at the top and a 'STEAM' inlet on the right. Both diagrams have 'BOTTOMS' labeled at the bottom.

Then, we look into this part that, if we look the reboiler right reboiler is one where this liquid is being boiled and then fed to the column right that is what it is being done. So, if this is the reboiler there is a steam coming in and from there the vapours are going out and some bottoms that may come out as the product right. This is more prominent in this that some bottoms are coming.

So, in this reboiler, this called kettle type reboiler steam is being introduced; steam is condensed right and your this liquid after boiling it is coming to the column yes, some vapours are also being introduced because when you are boiling some vapour also is formed. So, both liquid and vapour they are getting induced of course, it is mostly vapour because that feed which will come that will come as the liquid. So, more liquid is vaporized through this and that vapour is allowed to go out and this vapour will have more rather temperature than the feed temperature of the liquid, right.

However, there are number of designs of reboilers, they can be regarded as heat exchangers that are required to transfer heat, transfer enough energy to bring the liquid at the bottom of the column and that at the to the boiling point, right. So, another thing which is also very much required is called volatility, right.

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Out of that if we are saying that it is a binary mixture then out of the two, one A and B, the A is more volatile if than B then we can say that if A is more volatile than B, then we can say the volatility of a is more than that of the B; so, A will separate earlier than that of B if it is multi component then that is much much easier. So, that will be dictated by this diagram and this is called your, this is called boiling point diagram, right.

So, boiling point diagram if you look at if it is A and B right, then equilibrium compositions are available from here. In a liquid mixture whatever is there vary and that vary with temperature at a fixed pressure right. A liquid mixture containing the two components A and B there is a binary mixture, if we look at that then we see that at this point right and this is said mole fraction right X earlier we have said X_A , Y_A , where X_A is the liquid mole fraction and Y_A is the vapour mole fraction right.

And, if the mole fraction of A = 1; that means, it is all with A and it is at the boiling point and its boiling point is somewhere like this right whereas, if the mole fraction is 0 like here so, it is the point where it is the B at its boiling and that is corresponding to this A 110 and here it is somewhere you said 88, 89 whatever is coming right.



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The **dew-point is the temperature at which the saturated vapour starts to condense.**

The **bubble-point is the temperature at which the liquid starts to boil.**

superheated vapour

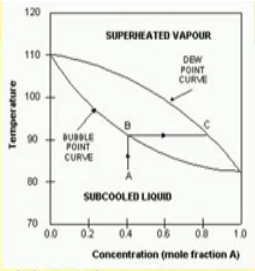
subcooled liquid.





Now, really what is happening that let us look into the next where we have taken this that there is a, ok here.

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- ❖ A = 0.4 (point A) is heated,
- ❖ The bubble-point (point B)
- ❖ Equilibrium composition
- ❖ Point C,
- ❖ @ 0.8 mole fraction of A.
- ❖ This is approximately 50% richer in A than the original liquid.



This difference between liquid and vapour compositions is the basis for distillation operations.



So, there is a; these are two curves one is called dew-point curve and another is called bubble-point curve. Obviously, dew-point curve is corresponding to the vapour because the vapours the point r condenser condensing and bubble point curve means bubble is being formed that is at boiling so, this is the liquid. So, this curve is for the liquid and that curve is for the vapour, right.

And, if we this part is called sub-cooled portion and this part is called super-heated portion. So, a portion of sub-cooled portion if you take right say at a point a you have taken 0.4 mole fraction and this is denoted as A, right. So, the from this the bubble-point that is point B where A is getting boiled off right, is getting boiled and it becomes an equilibrium right where the point C this is in equilibrium with the vapour and the liquid this is in equilibrium, right.

And, that the mole fraction of A at the point C is somewhere 0.8, right. So, from 0.4 mole fraction you have come to the mole fraction of 0.8. So, this is approximately 50% richer in A than the original liquid. So, you started with 0.4 came to 0.8, so, it is 50% richer. This is how the concentration curve or it is simply called your so, this is simply called your boiling-point curve right so, that can be used for the separation technique, right.

So, the difference between the liquid and vapour compositions is on the basis of is the basis for the separation of the in distillation, right.

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Relative volatility A and B, and hence their boiling points.

How **easy or difficult** a particular separation will be.

The relative volatility of component 'A' with respect to component 'B' is defined as

$$\alpha_{AB} = \frac{y_A/x_A}{y_B/x_B}$$

y_A = mole fraction of component 'A' in the vapour
 x_A = mole fraction of component 'A' in the liquid

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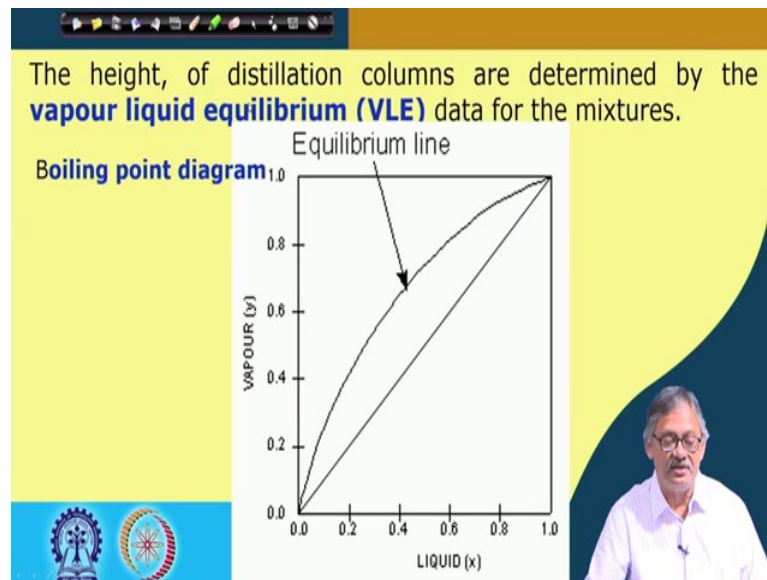
Then let us look at the other part that relative volatility which we I was saying earlier a little that relative volatility between A and B right so, that is because of the boiling point difference, right. Boiling point difference says the relative volatility or how easily or how quickly one can be separated out from the relative volatility we can judge right. A particular separation how long it will take or which one will separate first which one will

be relatively quicker or which one will be more. So, that can be accessed from the relative volatility between the two components A and B, right.

So, if we will look at the relative volatility of component A with respect to component B, then we can define it like this α_{AB} , where α_{AB} is the relative volatility = y_A / x_A that is the vapour mole fraction in the vapour of A vapour state of A by mole fraction of the A in the liquid state divided by mole fraction of B vapour of B by mole fraction of the liquid in B. So, it is that the relative volatility which will tell the value right.

So, where y_A is the mole fraction or of the component in the vapour for and similarly x_A is the mole fraction component of A in the liquid form, right.

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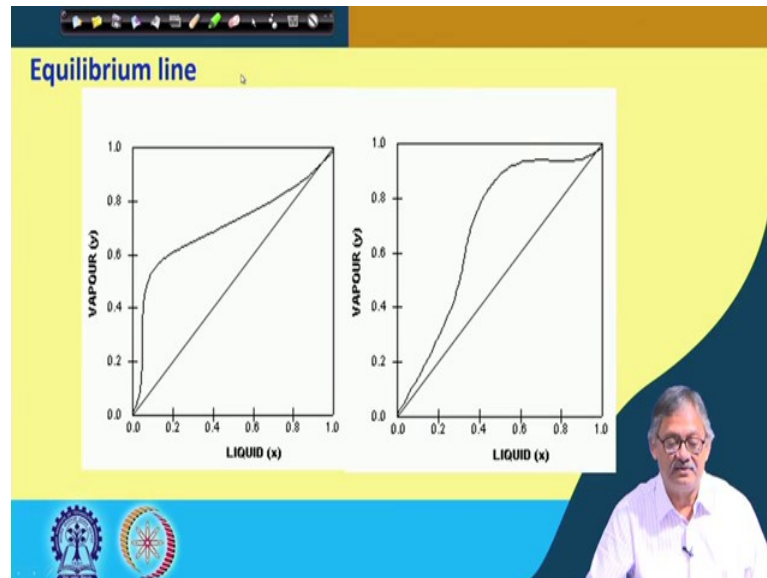


So, if that be true if we know the relative volatility, we can then utilize this vapour liquid equilibrium or VLE right that Vapour Liquid Equilibrium curve this we can utilize for the separation technique. The height of the distillation columns that can be determined by the vapour liquid equilibrium data for mixtures of A and B, right. This is called boiling point diagram from the boiling point diagram we can get it right and this is called the equilibrium lines.

So, vapour liquids if we plot that mole fraction of vapour of the component A, mole fraction of liquid of the component A, then we can plot and this is the separation line or

this is the straight line or called 45 degree line right, which we can utilize for the separation technique.

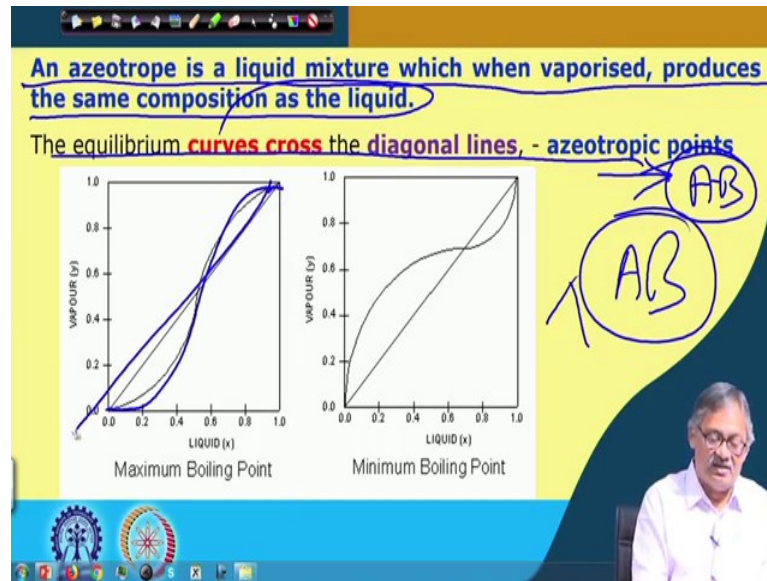
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But, that earlier we have seen that if we had x and y right of A of course or both of A and we have seen that there is a this teen good vapour liquid relationship right, that is easy to separate. But, if we look at these two curves you see the curve is like this, this curve is like that.

So, the vapour liquid relationships are your equilibrium lines are not that simple or so easy by which we can because in some portions you will see when you are doing in McCabe-Thiele or number of stages you were determining that time they will become more difficult for the separation, right. Whereas, this was much more easier for the separation to take place.

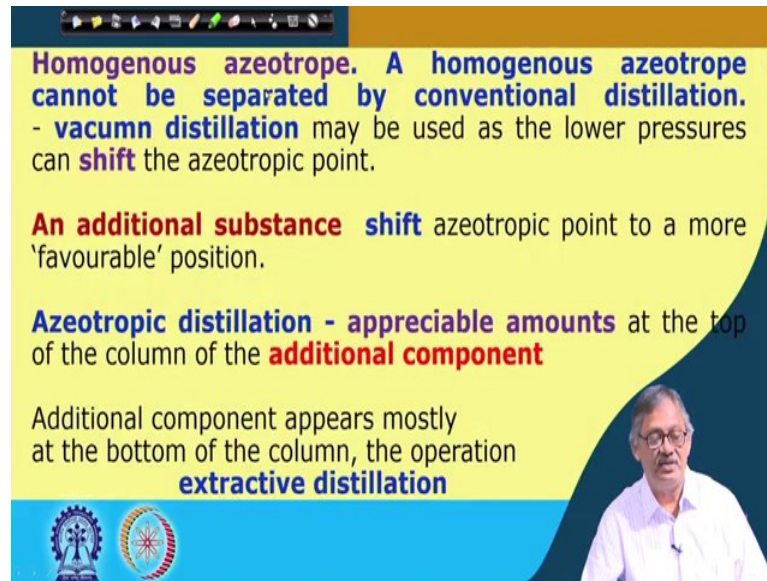
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Even more, it is even was when you look at this other curve like this is called azeotrope. You see the equilibrium curve right, this equilibrium curve an azeotrope is a liquid mixture which when vaporized, produces the same composition as that in the liquid right. So, this is the difficulty; when you have an azeotropic mixture or azeotrope, then whatever composition you had in the liquid as A B after separation in the vapour also you will get the same composition in the A B. So, it is very difficult to separate why you said that equilibrium curve like this the equilibrium curves is bisecting the diagonal, right.

So, this diagonal is being bisected by the equilibrium curve and they are called azeotropic mixtures right and this point is azeotrope, where the liquid and vapour is difficult to separate, right.

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Homogenous azeotrope. A homogenous azeotrope cannot be separated by conventional distillation.
- **vacuum distillation** may be used as the lower pressures can **shift** the azeotropic point.

An additional substance shift azeotropic point to a more 'favourable' position.

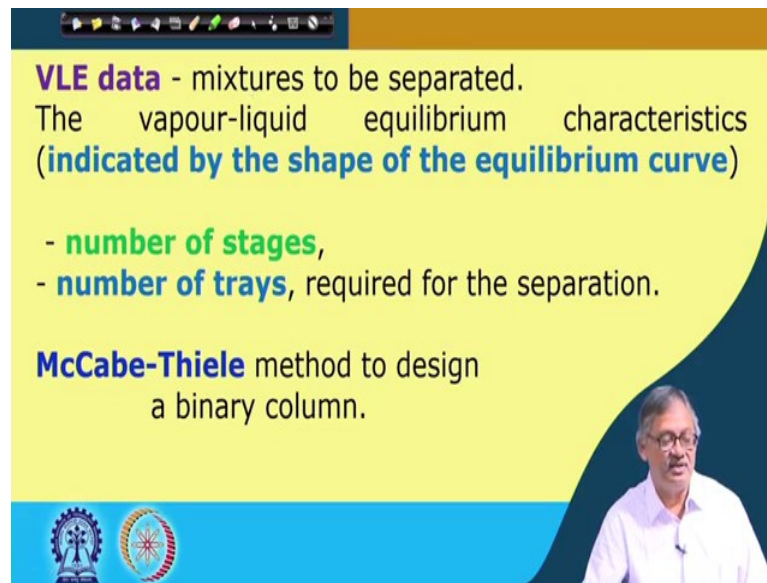
Azeotropic distillation - appreciable amounts at the top of the column of the **additional component**

Additional component appears mostly at the bottom of the column, the operation **extractive distillation**

For that what is needed that you may have to add some external substance or some by other trick you have to shift that azeotropic point to a more favorable positions, so that the separation can take place, right. This can be done by with some addition of some external substance right and that is what is known as extractive distillation, right.

Additional component appears mostly at the bottom of the column and the operation is called extractive distillation; whereas, azeotropic distillation is that where appreciable amounts at the top of the column of the additional component appears. Additional component appears at the top of the column and that is called azeotropic distillation or the reverse if it is on the bottom part or bottoms then it is called at the or it is called extractive distillation, right. So, azeotropic separation is a very difficult job right.

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VLE data - mixtures to be separated.
The vapour-liquid equilibrium characteristics
(**indicated by the shape of the equilibrium curve**)

- **number of stages**,
- **number of trays**, required for the separation.

McCabe-Thiele method to design
a binary column.

And, we have seen that VLE data right or vapour liquid equilibrium data that is a mixture of the two components and that is the basis for the separation, right. And, this vapour liquid equilibrium characteristics depends or that is on the characteristics on which your separation will take place and you can predict or you can know from the from the shape of the equilibrium curve, as we had shown earlier someone is like this or someone is like that instead of like this. So, from the shape of the equilibrium curve it is very easy to predict that how long how good the separation will be right.

Now, we have come to the end. So, perhaps we will complete it in the next class.

Thank you.