Mass Transfer Operations - I
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Lecture - 28
Distillation

Welcome to the 3rd lecture of module 5 of Mass Transfer Operation and in this module we are discussing Distillation operation. Before going to this lecture let us have small recap of our previous lecture. In our previous lecture we have mainly discussed 2 important things; one is deviation from ideality and azeotropes; deviation from ideality and azeotropes.

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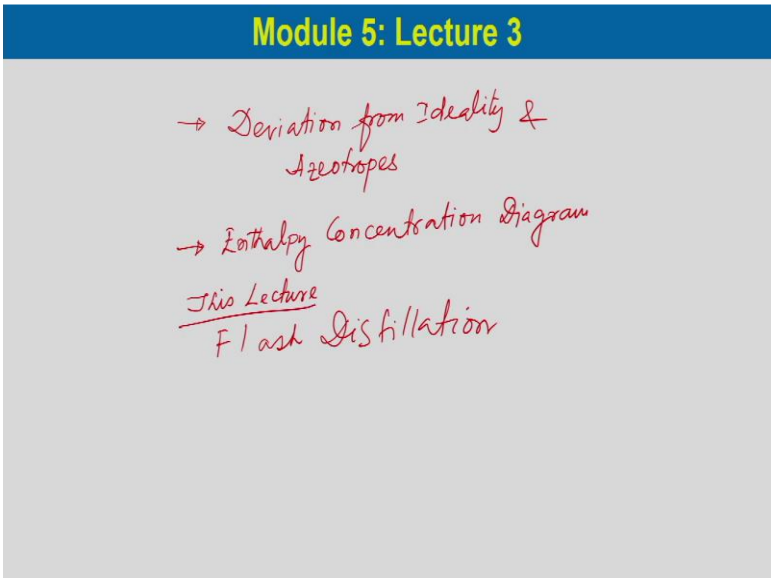

The second important things we have considered is enthalpy concentration diagram. Now, in this lecture we will mostly concentrate on the flash distillation. Let us define what is flash distillation.

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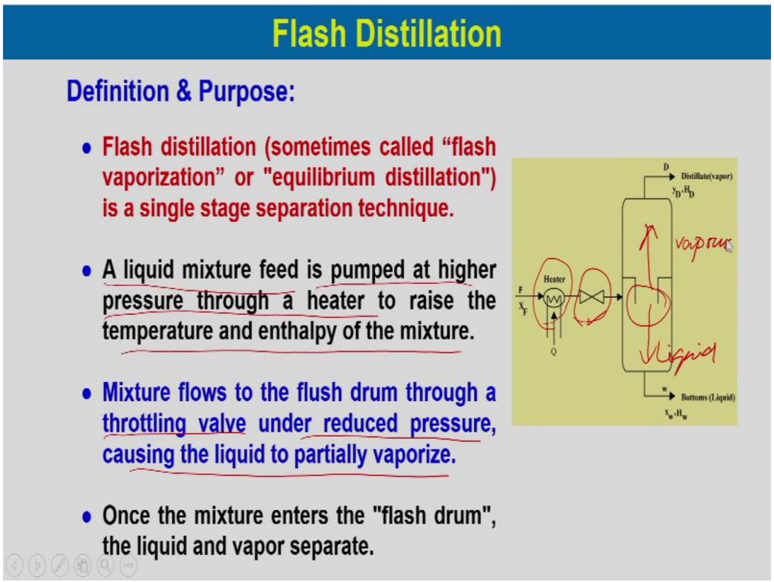

So, flash distillation sometimes are called flash vaporization or equilibrium distillation is a single stage separation technique by distillation. It is a single stage separation and you can see the typical flash distillation unit shown over here. In this case you have only one vessel steel vessel and you have feed into that and you can get the distillate at the top as the bottom products.

So, in this case what happens? A liquid mixture that is your feed which is pumped at higher pressure through a heater, so you have a heater over here there is a pump before it. So, through the heater it is pumped and in the heater it reach the temperature and then temperature as well as enthalpy of the mixture and then what happens; the mixture flows to the flash drum through throttling valve. So, you have a throttling valve, so once it is pumped through the heater, the temperature of the liquid mixture increases and then through the throttling valve it goes to the flash drum.

So, that is under reduced pressure, so from high pressure side to the low pressure side that is how the throttling is used over here. Because of this is the liquid gets partially vaporized, so which is entered into the chamber. Once the mixtures enters the flash drum the liquid and vapour separate. So, once the liquid at reduced pressure enters into the flash drum. So, there is a separation between the liquid phase and the vapour phase, so liquid comes down and vapour goes up.

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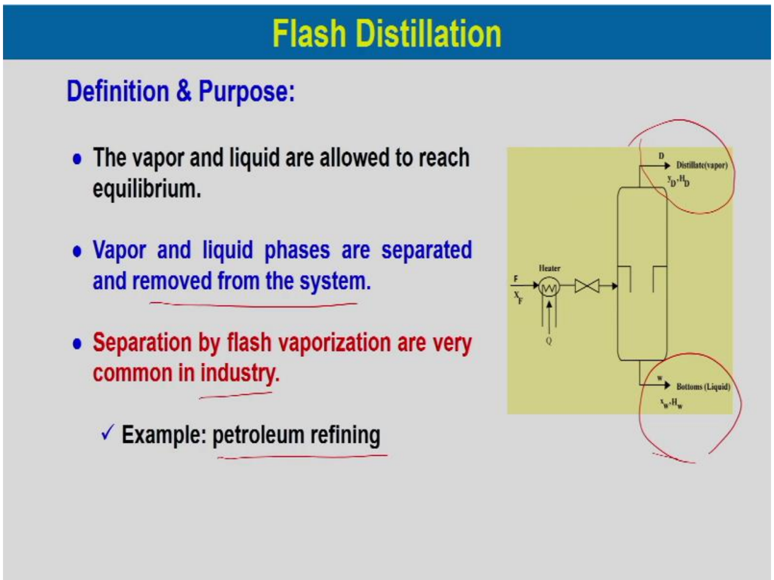

The vapour and liquid are allowed to reach equilibrium. So we need to give enough space so that the vapour and liquid they disengage and then they reach equilibrium. So, vapour and liquid phases are separated and remove from the system. So, the liquid is removed as a bottom product and the vapour is removed as a top product called distillate. So, separation by flash vaporization are very common in industry.

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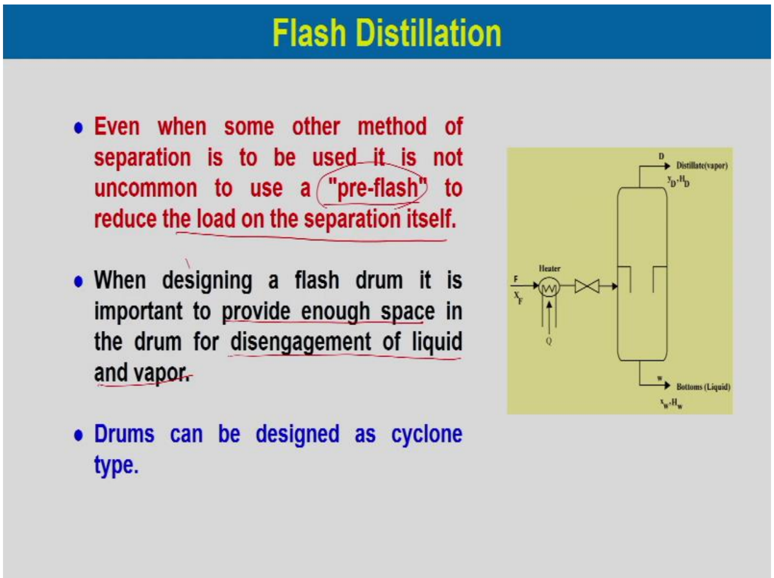

So, for example, petroleum refining it is extensively used this flash vaporization or even when some other methods of separation is to be used. It is not uncommon to use pre-flash to reduce the load of the separation itself. So, generally if you look into any separation process or you need to have a complete distillation tower before that you might have installed a pre flash. In this way we can reduce huge load to the main tower, can be used in different separation of pre flash as a method for other separation process.

When designing a flash drum it is important to provide enough space in the drum for disengagement of the liquid and vapour. It requires enough space inside the drum so that disengagement of liquid and vapour takes place which is very much important. Drums can be designed as cyclone type. If it is cyclone type what will happen? The liquid will goes to the valve on the cyclone and it falls down to the gravity and then the vapour goes up. So, significant separation can be achieved.

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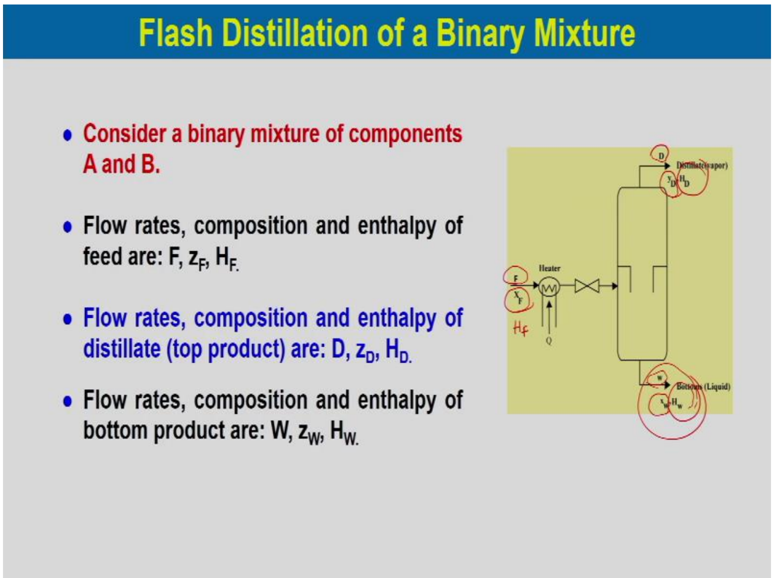

Now, consider a binary mixture of component A and B; two component system. We will discuss how the flash distillation of binary components. Now the flow rates, composition and enthalpy of the feed if we define the feed flow rate has molar flow rate say F and its composition X F, similarly it’s enthalpy would be H F. So, composition of the feed is given over here and then flow rates, composition and enthalpy of the distillate that is coming at the top product.

So, which is given over here the distillate molar rate flow rate is D it is a vapour, so vapour composition is y D and its enthalpy is H D. Then we have bottom products. The flow rates, composition and enthalpy of the bottom products which is shown over here, where you have W is the molar flow rate of the liquid which is coming out as a bottom product. Its composition of the solute is x W that is the lighter components and its enthalpy is H W. So, condition for a particular salute is given at feed distillate and the bottoms.

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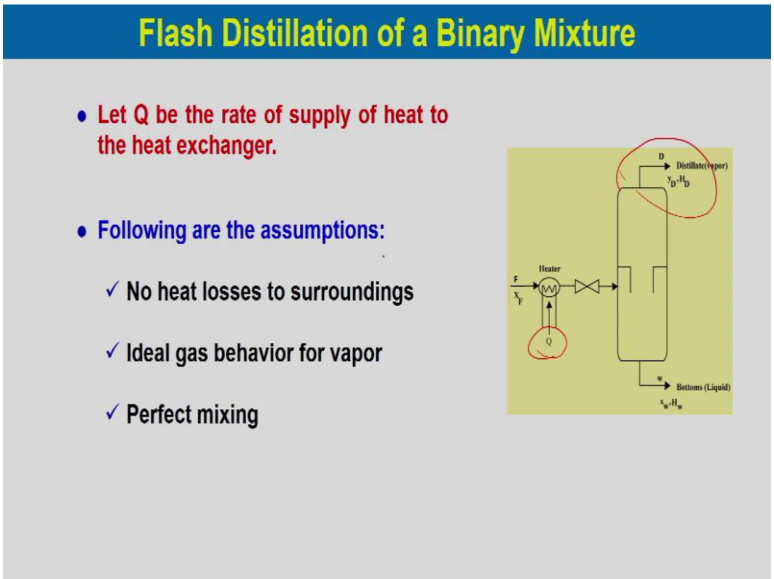

Now, let Q be the rate of supply of heat to the heat exchanger. So, if we supply the heat over here to preheat the heat at a particular temperature we need to supply some heat to this heat exchanger, let it be Q. Now we do the following assumptions no heat losses to the surrounding. So, assuming that it is insulated systems this things and there is no heat loss to the surrounding, so insulated system. Ideal gas behaviour for the vapour, so vapour which will generate over here should be ideal in nature and perfect mixing. So, mixing of the between the vapour and liquid there is perfect mixing.

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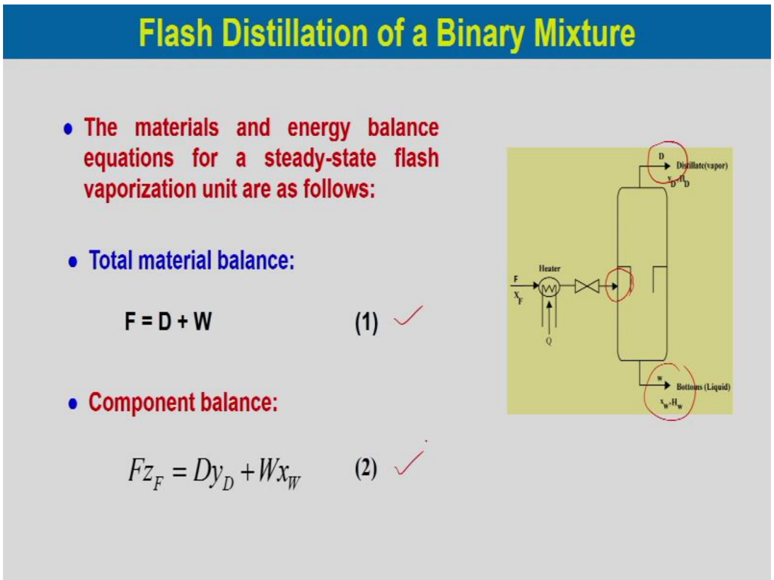

So, if we consider this three assumptions and then if we do the material and energy balance for a steady state flash vaporization unit, first we will do the material balance. So, feed is F mole F mole so per unit time and then you have a distillate flow rate which is D and you have a bottom flow rate of W. So, total material balance would be F is equal to so entering into the flash drum over here is F and out from the column is these 2.

So, rate of moles in would be equal to rate of moles out. So, if you do that F would be equal to D plus W, let us say this is equation 1. Now if we do the component balance, so component we have a over here which is more volatile component. So, having the total flow rate F and its composition of the more volatile component z F.

So, Fz F would be equal to distillate, flow rate into mole fractions of the solute is widely in the distillate plus W which is the bottom flow rate into the mole fractions in the liquid which is x W. So Fz F would be equal to Dy D plus Wx W, so this is equation 2.

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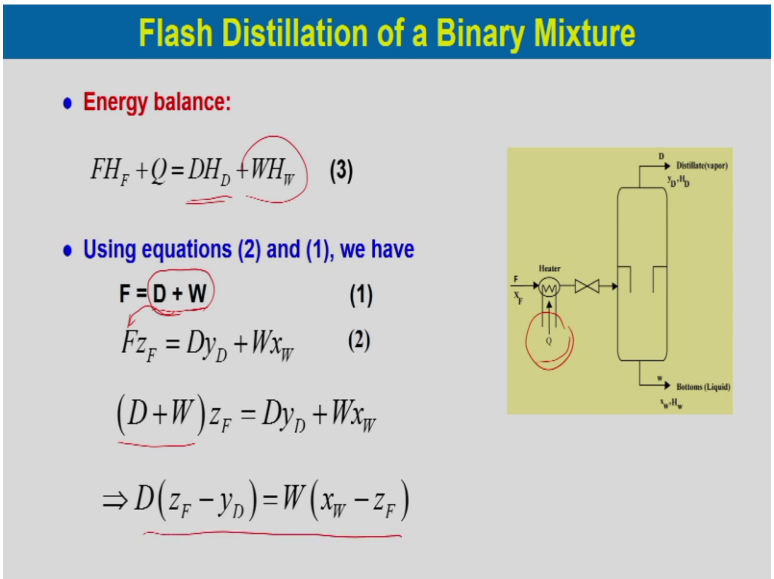

Now, let us do the energy balance. In this case you can see the feet has the enthalpy of H F. So, F into H F plus no heat which is supplied to the heater which is Q, so plus Q would be equal to enthalpy of H D; D into H D which is for the top product and then for the bottoms WH W. Since we have considered there is no heat loss to the surroundings, so the energy balance should be valid like this.

Now if we use the equation 2 and 1, the equation 1 is this, the total material balance and equation 2 is the component balance which is Fz F is equal to Dy D plus Wx W. Now using these two equation, if we just do the rearrangement; in place of F if we substitute D plus W, we will have D plus W plus into z F would be equal to Dy D plus Wx W. From this we can write D into z F minus y D would be equal to W into x W minus z F. Just multiply z F with these two terms and then do the rearrangement so you will obtain this.

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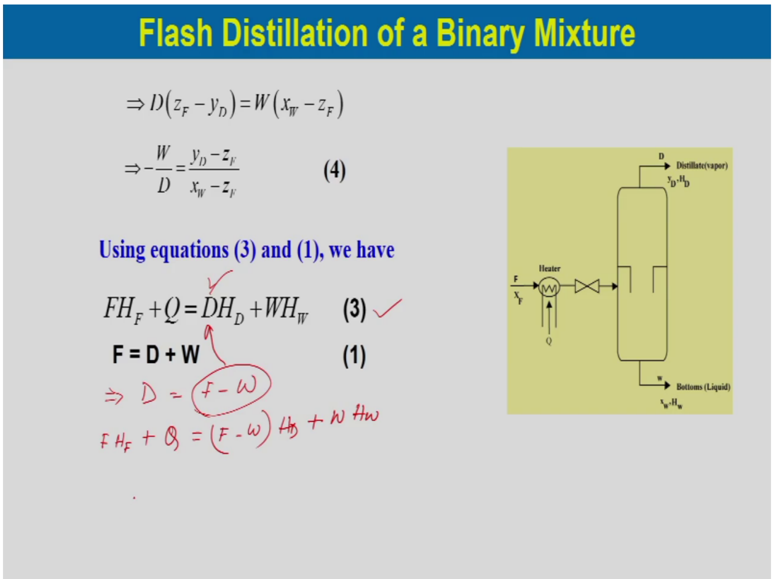

Now if you just simplify it again from this equation you will get minus W y D would be equal to y D minus z F divided x W minus z F. Similarly using equation 3 and 1 we have FH F plus Q that is the energy balance equation is equal to DH D plus WH W, that is equation 3 energy balance equation and equation 1 which is total material balance equation; F would be equal to D plus W.

Now if we substitute this D over here F we can write D is equal to F minus W. Now substituting this over here we would obtain F H F plus Q would be equal to F minus W H D plus W H W.

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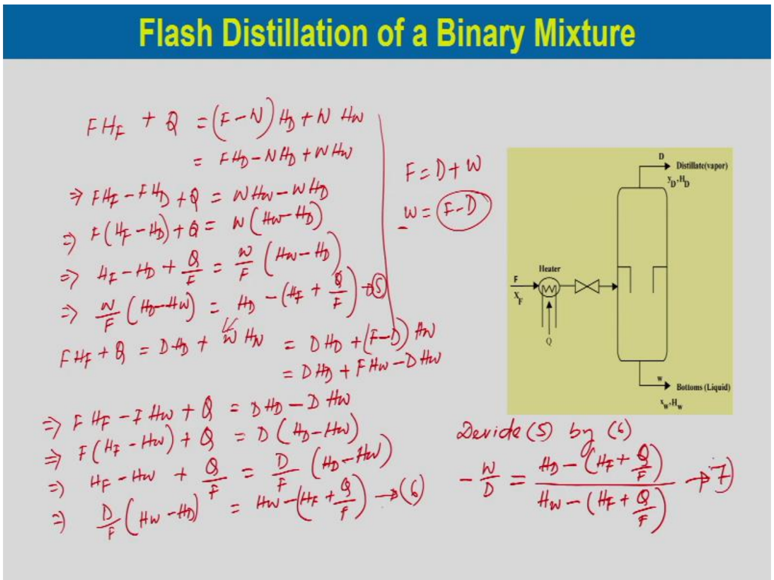

Now, if you just do the rearrangement that is F H F plus Q would be equal to F minus W H D plus W H W. So, from here we can write F H D minus W H D plus W H W. So, if you rearrange F H F minus F H D plus Q would be equal to W H W minus W H D. So, from here we can write F into H F minus H D plus Q would be equal to W H W minus H D. Now further rearrangement it would be H F minus H D plus Q by F would be equal to W by F into H W minus H D.

So, from here we can write W by F into H D minus H W would be equal to H D minus H F plus Q by F. Now if we just write the same equation again F H F plus Q would be equal to D H D plus W H W; so say this is equation 5. Now the total material balance F is equal to D plus W. So, W we can write here F minus D. From this we can write D H D plus F minus D.

So, in place of W we substitute F minus D, so we will have F minus D H W. So, we can write this thing as D H D plus F H W minus D H W. So, here if you do rearrangement F H F minus F H W plus Q would be equal to D H D minus D H W, then we can write F into H F minus H W plus Q would be equal to D into H D minus H W.

And again we can write H F minus H W plus Q by F would be D by F H D minus H W. So, from here we can write D by F into H W minus H D would be equal to H W minus H F plus Q by F, so say this is equation 6. Now if we divide 5 by 6, so divide 5 by equation 6. So, you will essentially obtain minus W by D would be equal to H D minus H F plus Q by F divided by H W minus H F plus Q by F; say this is equation 7.

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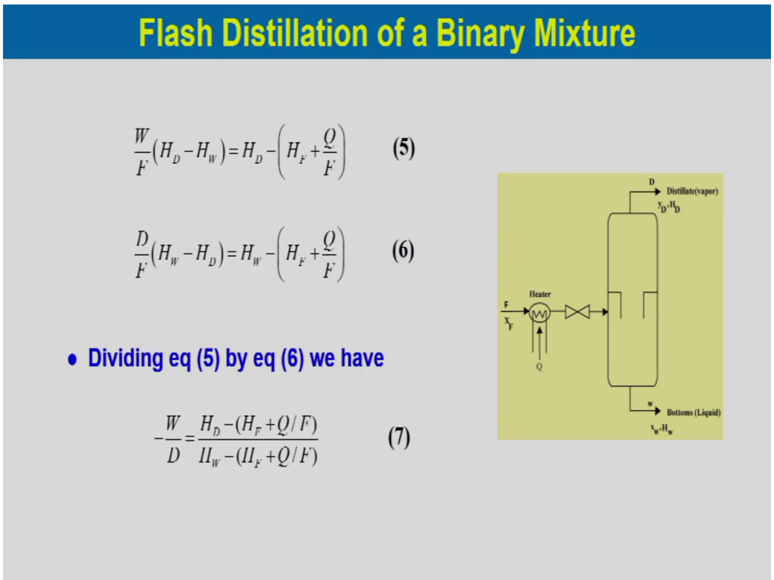

So, this is we have done this is equation 5, this is equation 6 and then we divide it and we obtained equation 7, so this is equation 7 which we have obtained.

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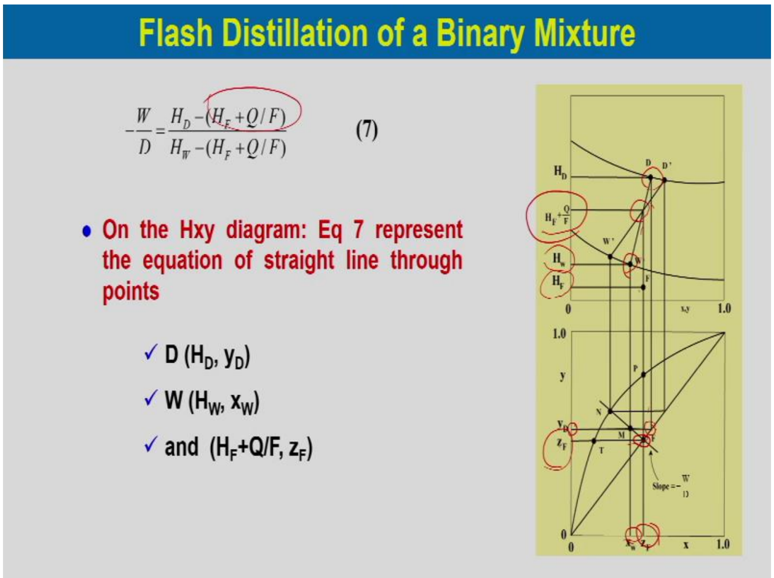

Now, if we look into the Hxy diagram so which is shown over here, the equation 7 represents the equation of straight line through points D which is over here is H D y D, so you could see this is you know y D. So, if you go straight to the x y curve that is mole fraction curve, so it will go to the 45 degree diagonal and then this is y D. So, point D represents x D, H D, y D on the enthalpy concentration diagram. And W which is over here it represents H W and corresponding mole fractions is x W here and also H F plus Q by F, so which is this part.

So, H F plus Q by F which is shown over here which is on the point between D and W; this is a enthalpy of that point and z F that is the feed condition which is given over here. So, if you come down here from here and so you have H F and then you can come down to the 45 degree diagonal you can have z F, so it is on the 45 degree diagonal and having the composition z F; z F.

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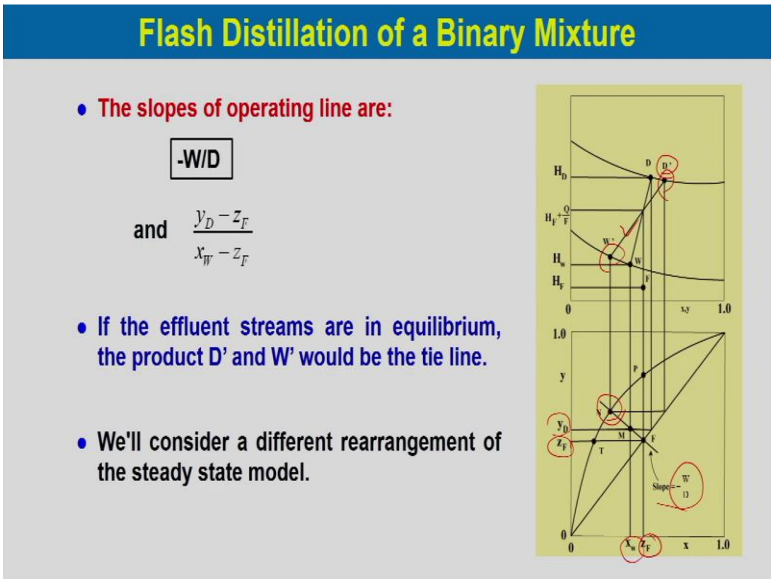

Now the slope of the operating line are minus W by D which is shown over here and the other slope for this line is basically y D minus z F which is y D minus z F divided by x W minus z F. So which will be a negative again because z F is more than know x W. If the effluent streams are in equilibrium the product D dash and W dash which is shown over here.

If they are in equilibrium you can see that you come down from this line from this point to the curve this is the intersection point with the slope minus W by D it intersects the equilibrium line at this point. So, the product if they are in equilibrium so you will obtain D dash and W dash. So, this will represent is the tie line. So, we will consider a different arrangement of the steady state model.

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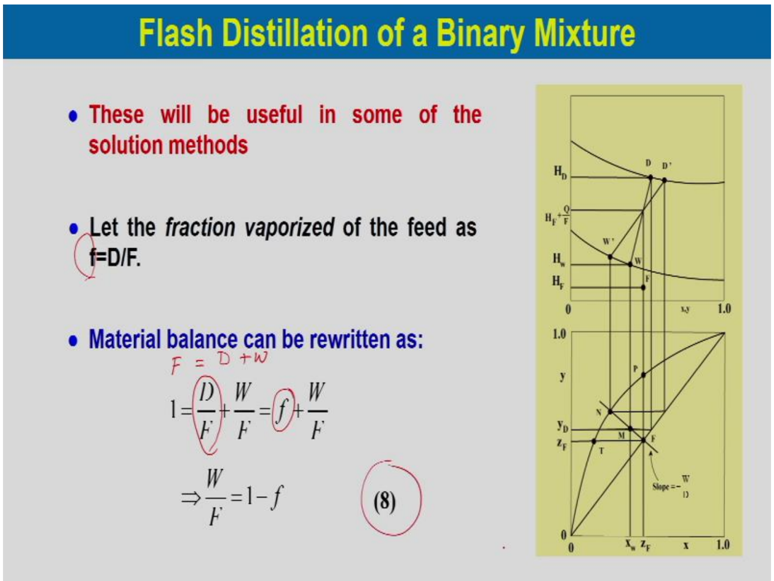

This will be useful in some of the solution methods, let the fraction vaporized of the feed as f. So, it is not completely vaporized and considered that it is fraction of the feed is vaporized and that fraction is defined as f is equal to D by F, so D the distillate and F is the feed. Now if we write the material balance, we can write from the overall material balance whatever we have written. So, 1 would be equal to be D by F plus W by F.

So, basically F is equal to D plus w. So, if we divide both sides with F, so this should be 1 would be equal to D by F plus W by F. So and this D by F we have defined as f, that is fraction vaporized plus W by F. If you just rearrange this equation, so it will be W by F would be equal to 1 minus f. So, this is equation 8.

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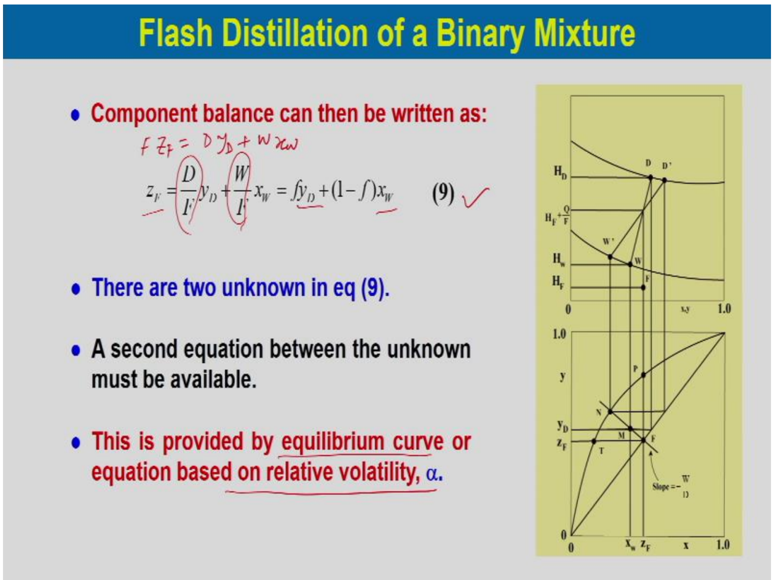

And from the earlier component balance we can write that is F z F is equal to D y D plus W x W. So, this is the balance equation. Now if we divide both sides by F that is the feed, then it would be z F would be equal to D by F y D plus W by F x W which would be equal to f this is a fraction vaporized D by F fy D plus W by F we have calculated is 1 minus f, so plus one minus f x W, so this is equation 9.

Now there are 2 unknown in equation 9; one is y D and x W. So, we need a second equation between these two unknowns which would be available and so that we can use this equation to calculate the enthalpy concentration diagram and solve the problem. So, to do that there are two options available with us; one is equilibrium curve. If equilibrium data is available, then we will have equilibrium curve or it can be based on the relative volatility equation that is alpha. So, either of these two should be available to relate between these two compositions y D and x W.

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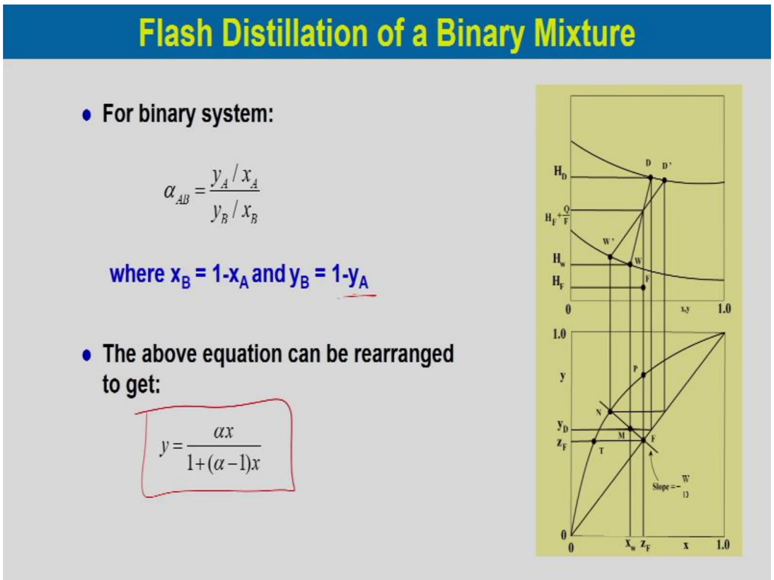

Now, for a binary system as we have already discussed alpha AB would be equal to y A by x A divided by y B by x B. So, x B would be equal to 1 minus x A and y B would be equal to 1 minus y A. So, the above equation can be rearranged to get y would be equal to alpha x divided by 1 plus alpha minus 1 into x.

So, this is the relative volatility equations, knowing the value of alpha and we can have yes any values of x and we can find out y. So, this equation can be used to find out the x y relation or the equilibrium curve, so that the problem can be solved.

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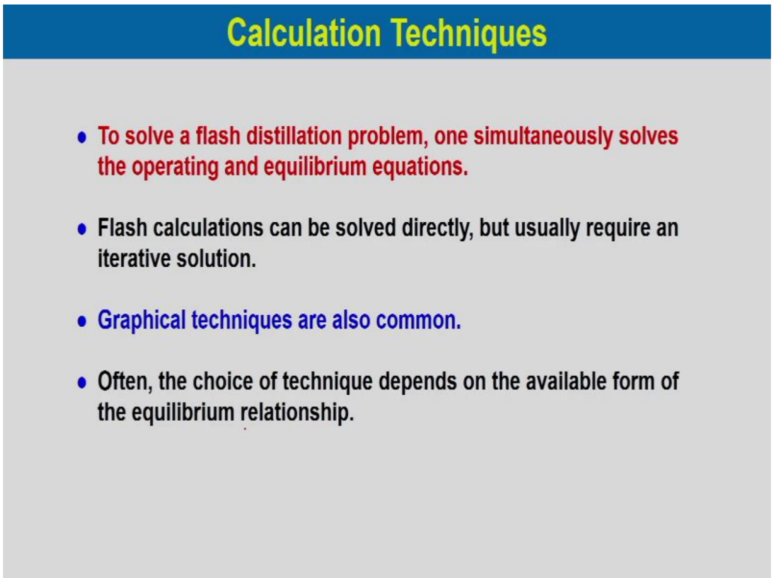

Now, the flash distillation unit the calculation procedures are very simple. To solve the flash distillation problem, one simultaneously solves the operating and equilibrium equation. So, operating curve equations also we need at the same time we need the equilibrium equations. Flash calculations can be solved directly, but usually required some iterative solutions.

Graphical techniques are also common for calculation of the flash calculation. Often, the choice of technique depends on the available form of the equilibrium relationships. So, depending on the data available or the relationship available the choice of the techniques will depend whether it will be analytically or we should go for graphically.

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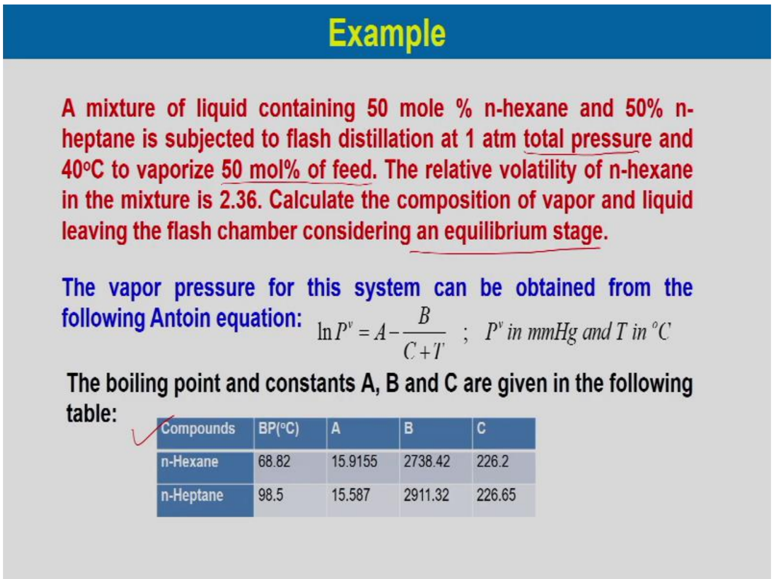

Now, let us take an example to find out vapour and liquid composition which is coming out from a flash chamber. Know a mixture of liquid containing 50 mole percent n hexane and 50 mole percent n heptane is subjected to a flash distillation at 1 atmosphere total pressure and 40 degree centigrade temperature to vaporize 50 mole percent of the feed, so 50 percent is vaporized. The relative volatility of n hexane in the mixture is 2.36. Now we need to calculate the composition of the vapour and liquid leaving the flash chamber considering an equilibrium stage.

The vapour pressure for this system can be obtained from the following Antoin equation. So, this is the equation Antoin equation which is similar the problem we have taken which we have discussed in the first lecture those same example that is know n hexane and n heptane mixture. The boiling points and their constant values for this Antoin equation is given over here which is in this table, so for n heptane and n hexane.

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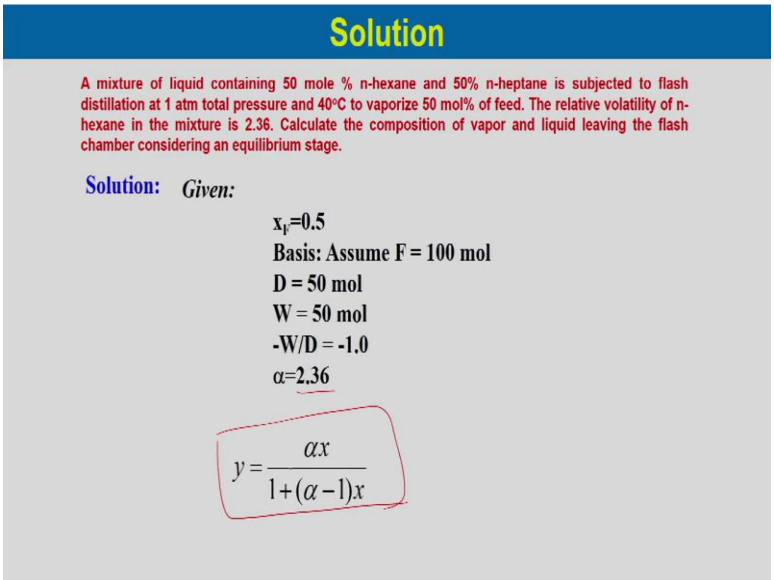

Now the data which is given x F is 0.5; 50 percent; so 50-50 mole percent and for the basis assume that feed is 100 mole. So, the distillate would be 50 mole because 50 mole percent n hexane and then bottom W would be 50 mole. So, minus W by D that is the slope would be 50 divided by 50, so it would be minus 1, so slope is minus 1.

Now relative volatility is given alpha, so which is 2.36 and this is the relation between the vapour and liquid composition that is relative volatility equation. So, once we know alpha we can get the x y data, so we can plot the equilibrium curve.

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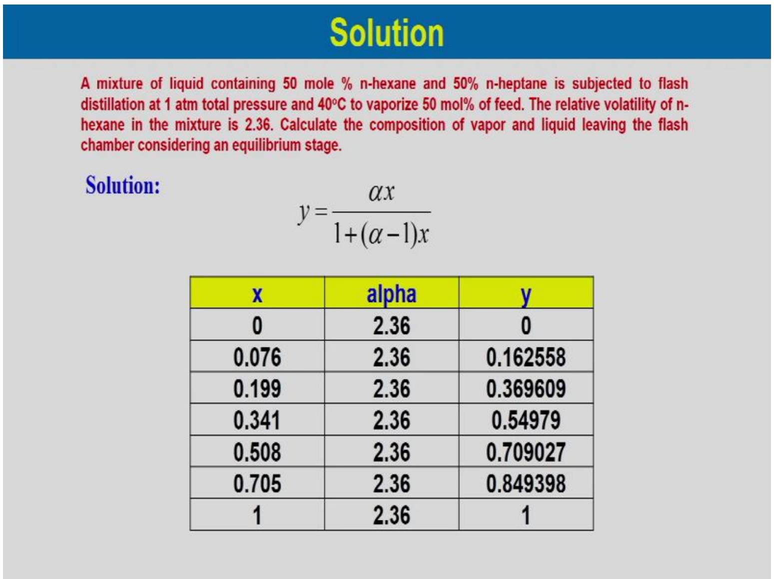

x	alpha	y
0	2.36	0
0.076	2.36	0.162558
0.199	2.36	0.369609
0.341	2.36	0.54979
0.508	2.36	0.709027
0.705	2.36	0.849398
1	2.36	1

So, data using this alpha values and x varies from 0 to 1 and y varies from 0 to 1. So, we can calculate the x and y values and we can plot the x y diagram.

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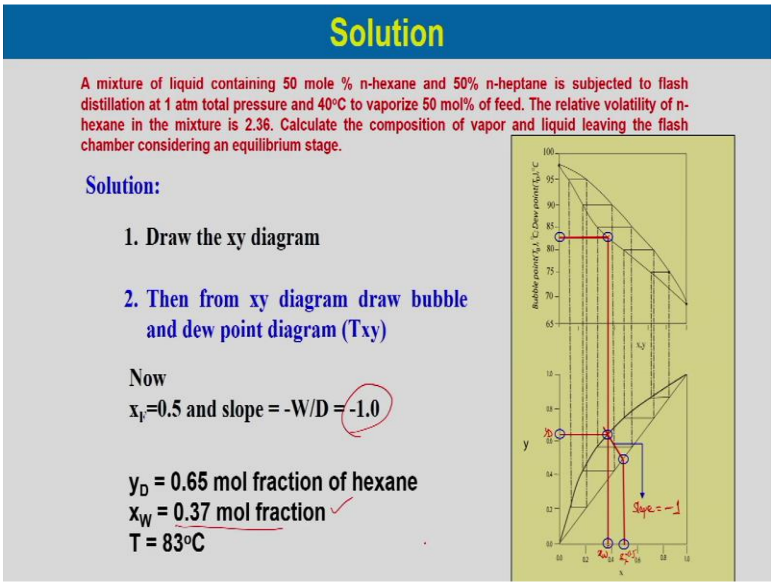

So, you can see over here the x y diagram are shown over here. First we need to draw the x y diagram. Then as the bubble point, boiling point, are given for both the components and their Antoin equation is given to calculate the vapour pressure. So, either from there or from here we can plot the T x y diagram that dew point curve and then bubble point curve we can draw over here as shown because it is the same examples which we have taken during the first lecture, so you can see the same figure you can obtain over here. Now we have feed is 0.5; the x F is 0.5 is 50 mole percent of n hexane and slope we have calculated which is minus 1.

Now with z F is equal to point 0.5 we can locate a point here. So, once we get the point on the x axis of x y curve then we can just go vertically and locate on the 45 degree diagonal of the x y diagram. This point is known, we obtain and so we can identify this point and which corresponds to z F is equal to 0.5. Now we can plot with this slope minus W by D is minus 1, from this point slope of this line is equal to minus 1. So, with minus 1 slope from this point you can plot this line which intersects the equilibrium curve at this location.

So, we can locate the intersection point between this line with that slope and the intersection point on the equilibrium curve and then go horizontally to the y axis to calculate at this point you will get y D, so here it is y D. So, you can calculate y D which is about 0.65 mole fraction of hexane. Now you can get the composition of the distillate which is y D. Now, what would be the bottom composition of the n hexane? So, now, from this point you just go vertically down to the x axis you would obtain that is x W, so which is over here. So, you will get x W is about 0.37.

So, once you calculate y D and x W, now we need to calculate the temperature of the mixture at bubble point temperature. So, to calculate the bubble point temperature what we need to do? We need to draw a vertical line from this intersection point and which will meet the bubble point curve at this location over here. So, which is shown over here, so which intersect the bubble point curve here. From this intersection point between the bubble point curve and the vertical line drawn over here, you go horizontally from this point, move horizontally to temperature axis and to get the bubble point temperature which will meet at this location.

You would obtained is bubble point temperature T which is about 83 degree centigrade temperature. So, this way we can solve the flash distillation problem for a binary mixture. So, with this I conclude this lecture. Thank you for attending this lecture and patience hearing and we will continue our discussion on distillation operation in the next class.