Mass Transfer Operations I
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Module - 5
Distillation
Lecture - 10
Multistage Batch Distillation with Reflux

Welcome to tenth lecture of distillation; this is module 5, and we are discussing distillation.

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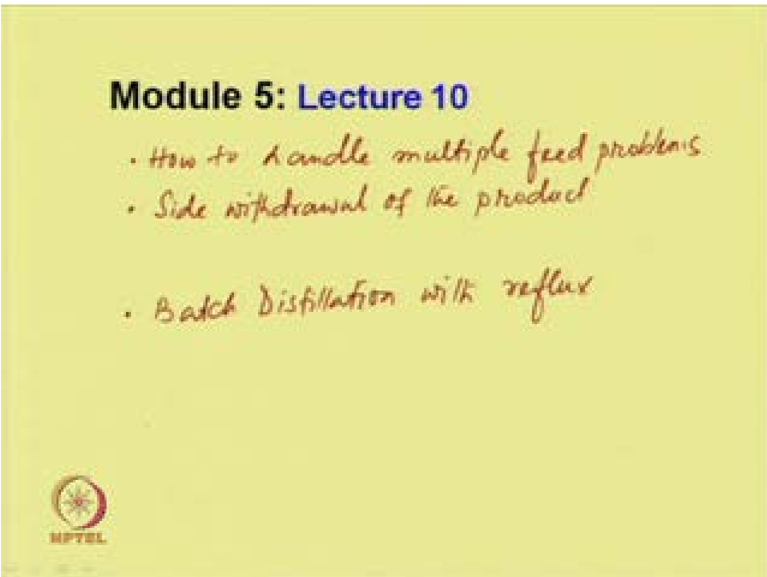

In our previous lecture, we have discussed how to handle multiple feed problems and also we have discussed side withdrawal of the product, side withdrawal of the product. Particularly, we have discussed if there are multiple feeds then what will be the material balance for a particular problem, and how to calculate the number of ideal stage required for a given separation, also to locate the different patria locations in the column. Similarly, if there is a side withdrawal of the product including the override distillate withdrawal then how the material balance will change, and what would be the operating equations and then how to find out the locations of the plate from where the product is withdrawn. In this lecture, we will mainly focus on another important topic that is batch distillation with reflux.

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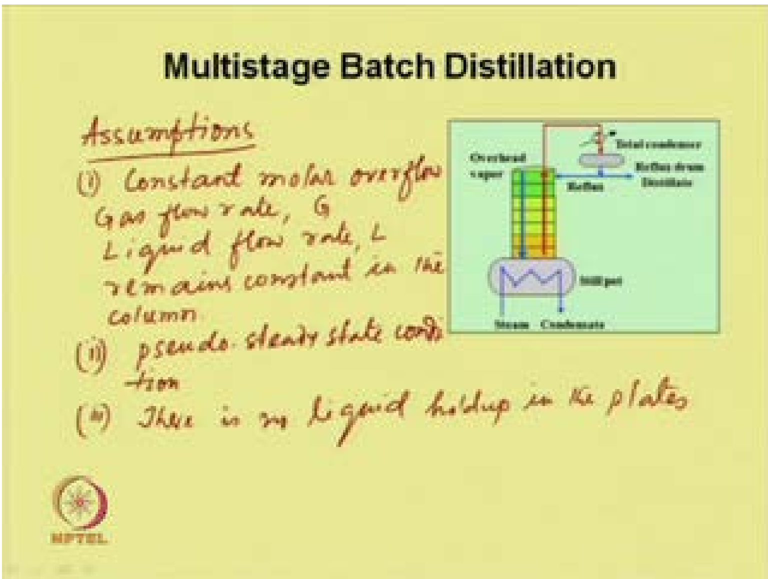

So, let us see a schematic of the batch distillation with reflux. This is a still pot, where the feed is taken over here and steam is injected and which is through a coil and taken as condensed state at the outlet, so that the energy is transfer to the feet to boiler. So that, the vapor forms and it goes off from tray to tray, and then there is similar to the fractionators, there is a top total condenser then reflux drum and then we have a distillate out and the reflux back to the column. We can chose how many stages we require for a given separations. As we can see the purity of the product is governed by the concentration of the feet and the fractions distilled out, which is taken out. Whatever we want the product purity can be achieved if we use the multi stage and we can get more pure products.

Now, in this case we will assume the similar to fractionators that is constant molar overflow; that means, the gas flow rate and liquid flow rate remains constant in the column. And second thing, we will assume pseudo steady state conditions maintained, pseudo steady state condition in general the batch distillation is a unsteady state process, but we will assume pseudo steady state condition. And third there is no liquid holdup in the plate, there is no liquid holdup in the plates. So based on these three primary assumptions, we will do the theoretical analysis of the multistage batch distillation problem with reflux.

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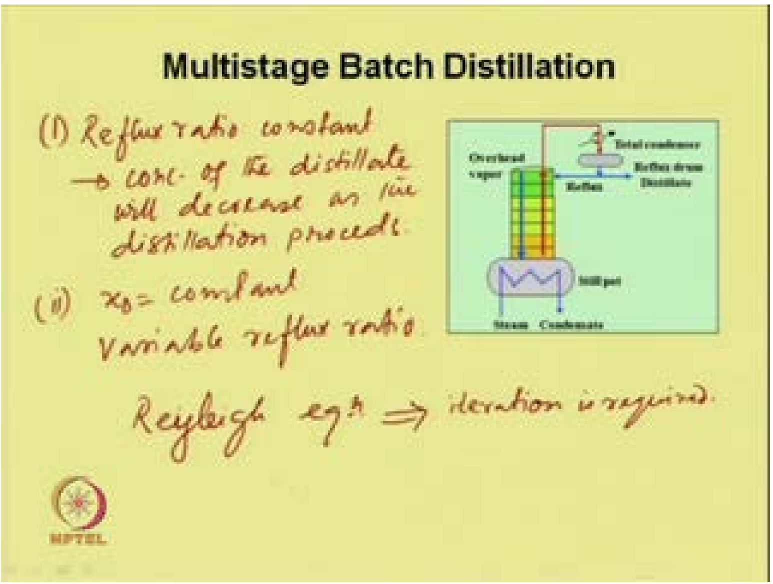

Now, this multistage batch distillation can be operates with two types. One is we can keep the reflux rate constant or reflux ratio constant, reflux ratio constant that is case one. So what will happen in this case, the concentration of the distillate will decrease as the distillation proceeds. And second we can keep the override distillate concentration constant that is x D constant, x D constant the reflux ratio will change, so variable reflux. So, the first one is known as the constant reflux operations, and the second one is known as the variable reflux operation. If we want to solve using the Rayleigh equations as we discussed before, then some iteration is required, and if you use the McCabe Thiele method of diagram, and we can obtain some of the information, which will be used for this iteration.

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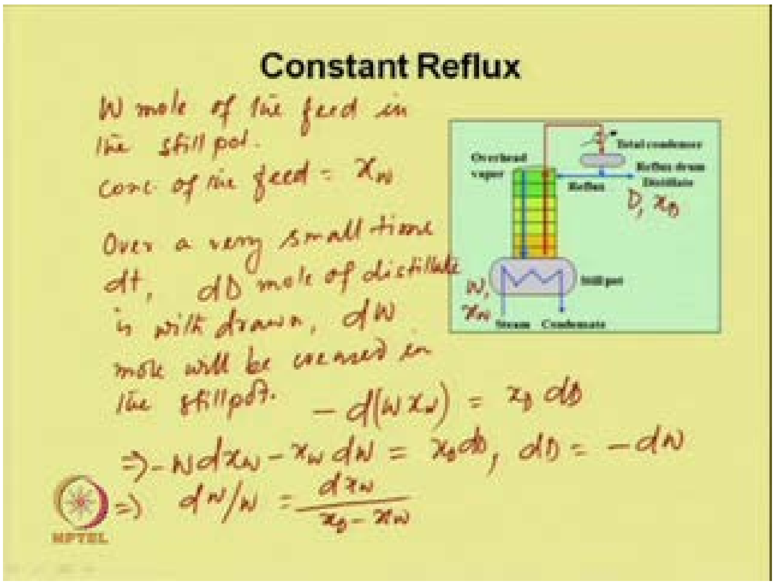

Now let us consider the first case which is constant reflux operation. We will discuss constant reflux operations. We have taken say W mole of the feed in the still pot, and its concentration of the feed is x w. Assume very small time free out over a very small time delta t – dt, dD is the distillate and this is the W and its x D and its composition is x w.

So, if dD mole of distillate is withdrawn, so the amount in the still pot which will also decrease by an amount dW mole will be decreased in the still pot. So, if we do the balance minus d W x w would be equal to x d dD from where we can write minus W d x W minus x w dW would be equal to x d d and we know that d d is equal to minus d W x d dD. And we know that dD would be equal to minus d W. So, we can substitute this one over here and which would be d W by W would be d x w divided by x d minus x w.

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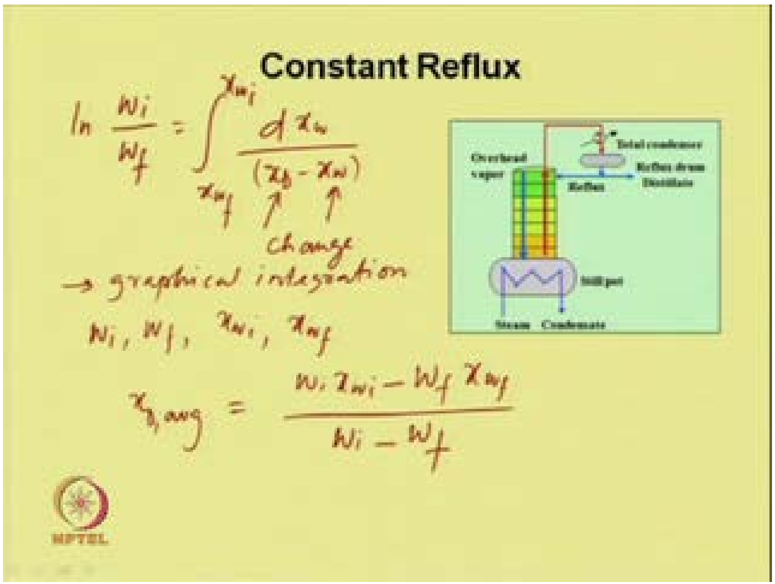

If we integrate over the concentration range from the initial to the final, we would be able to get l n W i by W f is the final concentration would be equal to integral x W f x W i d x w divided by x t minus x w. So, as the distillation would occur this x d and x w this will change. So, the integral of this can be evaluated graphically. So, graphical integration can be done to evaluate this integral, this we will discuss in detail with an example. In this, we have four terms W i, W f, x w i, and x w f; any three of this if known to us then we could be able to calculate the others. And the concentration of the distillate can be obtained from the following expression x D average, we could able to obtain W i x w i minus W f x W f divided by W i minus W f.

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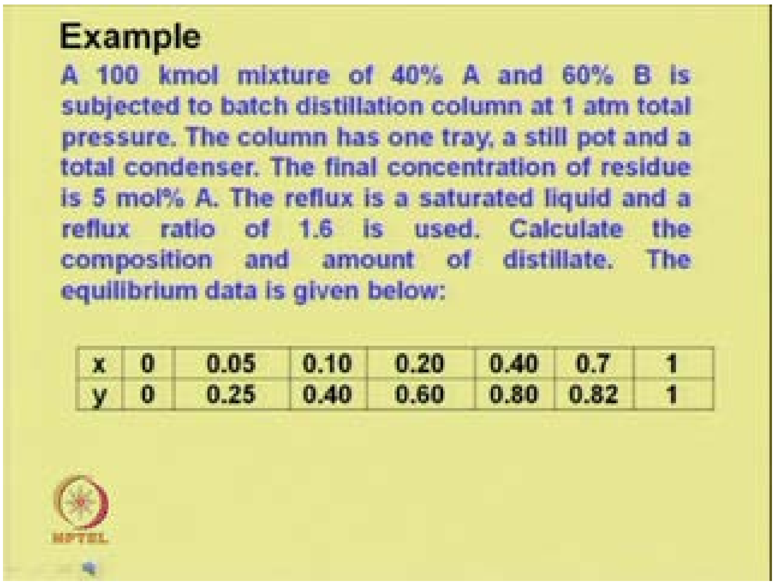

Let us consider an example, how to solve this problem. A 100 kilo mole mixture of 40 percent A and 60 percent B is subjected to batch distillation column at one atmosphere total pressure. The column has only one tray, or still pot and a total condenser. The final concentration of the residue is 5 mole percent A. The reflux is a saturated liquid and a reflux ratio of 1.6 is used. Calculate the composition and amount of distillate. The equilibrium data is given over here. So, the reflux ratio which is fixed at 1.6 and equilibrium data is given. So, we could able to plot the equilibrium curve. Since the concentration of the vapor from top tray will gradually decrease.

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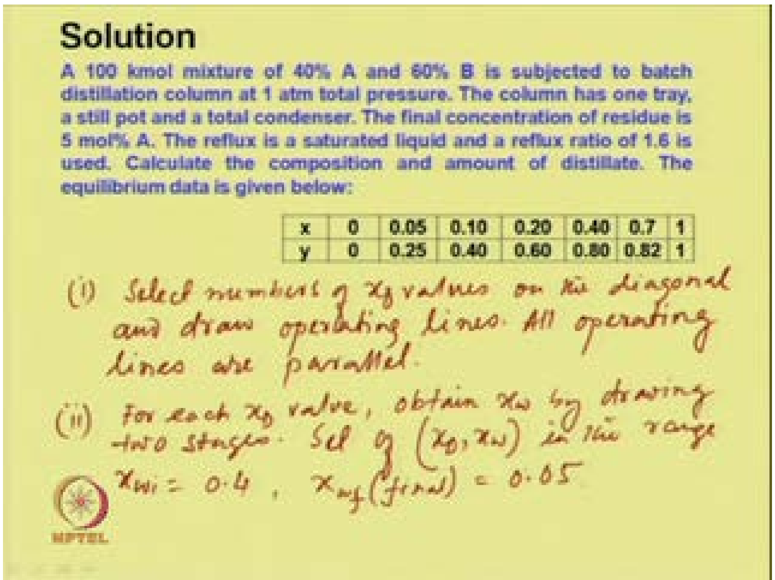

The procedural of solving this problem will be like this. Select number of x D values on the diagonal and draw operating lines. Since, the reflux ratio remains constant that is constant reflux operations all the operating line will be parallel because their slope is constant which is r by r plus 1. All operating lines are parallel. Second, for each x D values obtain x w by drawing two stages, two stages means we have one tray and one still pot. So, we will consider still pot as one tray, as we considered in case of the fractionators, the re-boiler as one stage, so it will be one equilibrium stage.

In this case, we will draw two stages and we will obtain the values of x w corresponding to a particular value of x D. We will have a set of x D, x W values. This will be in the range x w i would be which is initial that is 40 percent – 0.4, and the final x w f which is final would be 0.05. So, this is the final and this is the initial the mole fractions in the liquid phase. So, within this we would get a set of x D and x W.

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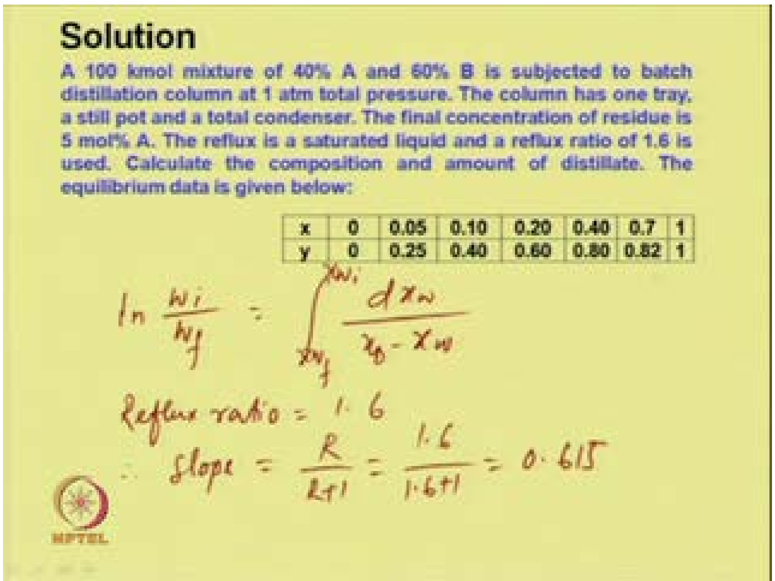

And then the integral equations, we know l n W i by W f would be equal to W f to W i x w f to x w i dx w divided by x D minus x w. And the reflux ratio is given 1.6, therefore slope would be equal to R by R plus 1 which is equal to 1.6 divided by 1.6 plus 1 which is equal to 0.615.

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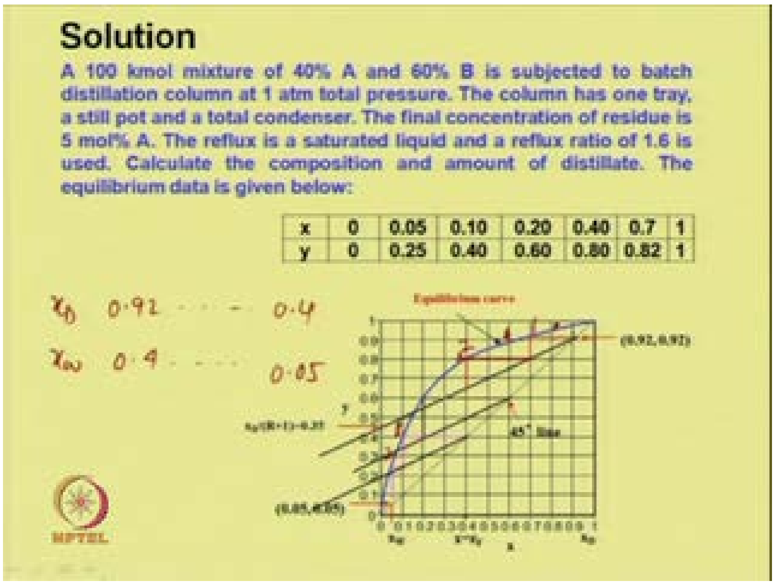

Now, from the equilibrium data we can draw the equilibrium line assume. This is the initial x D values is 0.92, two trays we can draw and there is composition is giving 0.4. So for this 0.92 and we could obtain that is x D and x w we could obtain 0.4. Similarly, at the end, we can see if we start at 0.4, so if we plot two number of stages one and two. So, you could obtain 0.05, so we could obtain 0.4 and 0.05. So, this is x D and x W data.

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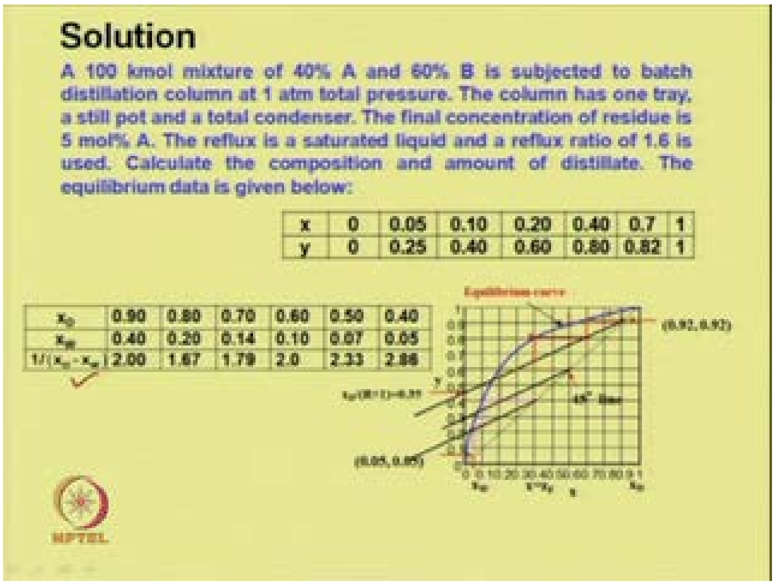

Drawing several similar parallel lines we have obtained x D and x W values, and from which we have calculated 1 by x D minus x W these are the values of 1 by x D minus x W. Now, we can plot 1 by x D minus x W verses x W to get area under the curve.

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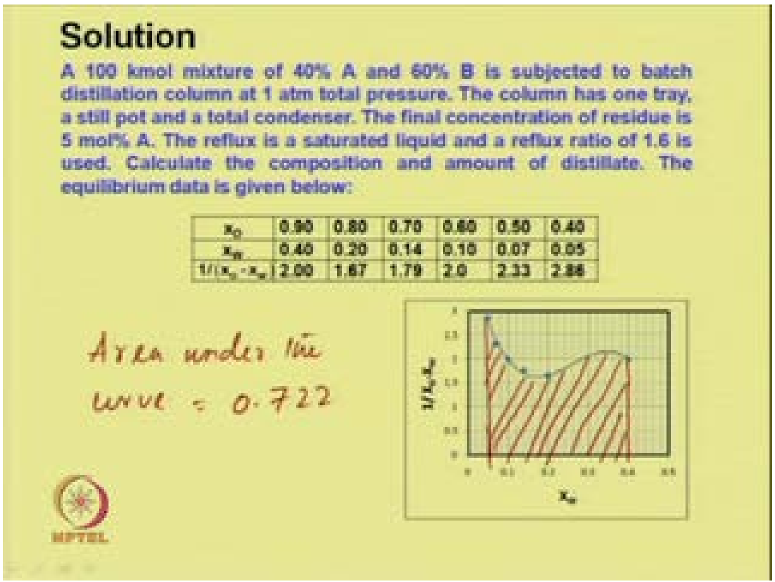

So, which is plotted over here and the area between this, so area under this curve, this is by any method we can obtain the area 0.722. So, area under the curve we can obtain.

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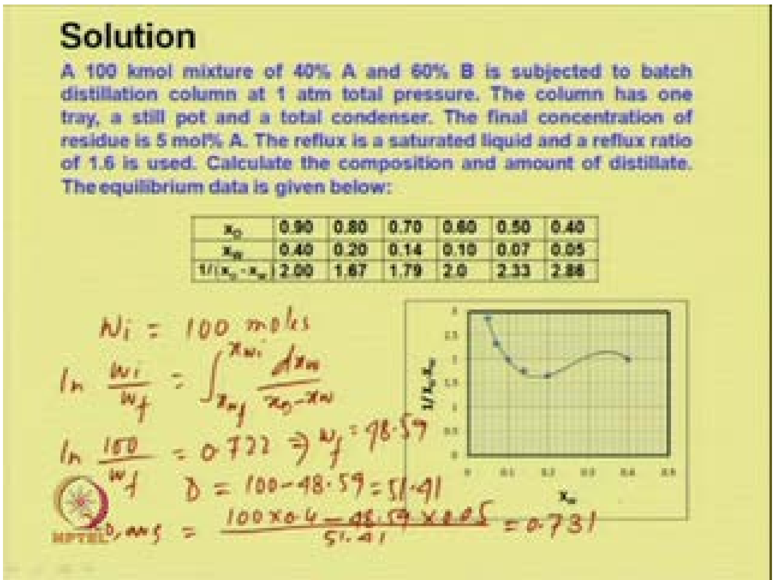

And then we know the initial amount of moles taken. So, W i which is 100 mole and we know l n W i by W f is equal to integral x w f x w i d x w by x D minus x W. So, here we can substitute l n 100 by w f is equal to 0.722 and from here we can calculate W f is 48.59. Then we can obtain D using the total material balance equations. So, it would be 100 minus 48.59 which is equal to 51.41. And average concentration x D average which would be 100 into 0.4 minus 48.59 multiplied by 0.05 divided by 51.41 which would be around 0.731; that means 73.1 percent is the distillate compositions.

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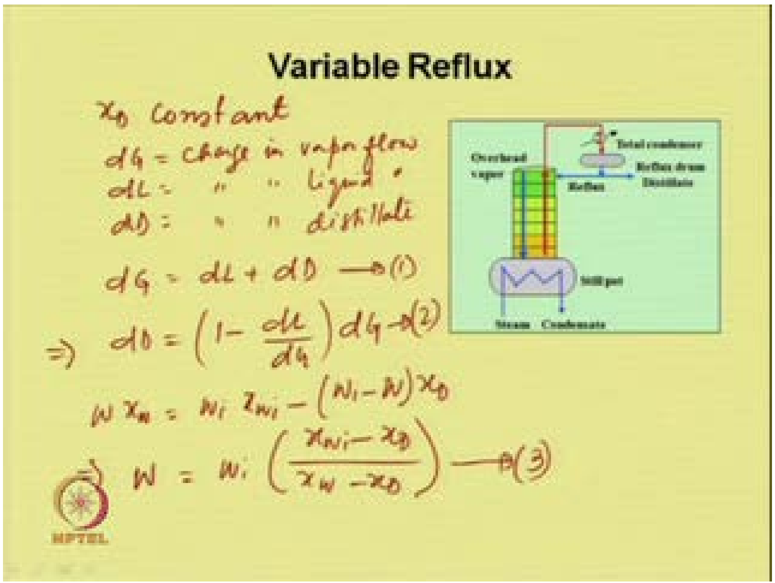

Now, we will consider variable reflux problem, where we are keeping constant overhead concentrations, so x D constant. In this case, the reflux ratio would be changed continuously where as keeping the x D constant, so the concentrations of the distillate will not fall any time; however, the reflux ratio will change continuously. Now say d G is the change in vapor flow, and d L change in liquid flow, and d D change in distillate withdrawal. If we do the total material balance, we can write d G would be d L plus d D. Just rearrange these equations, we can write d D would be equal to 1 minus d L by d G into d G. Now if we do the sepsis mole balance, we can write W x w would be W i x w i minus W i minus W into x D. So, from here we can write W is equal to W i x w i minus x D divided by x w minus x D.

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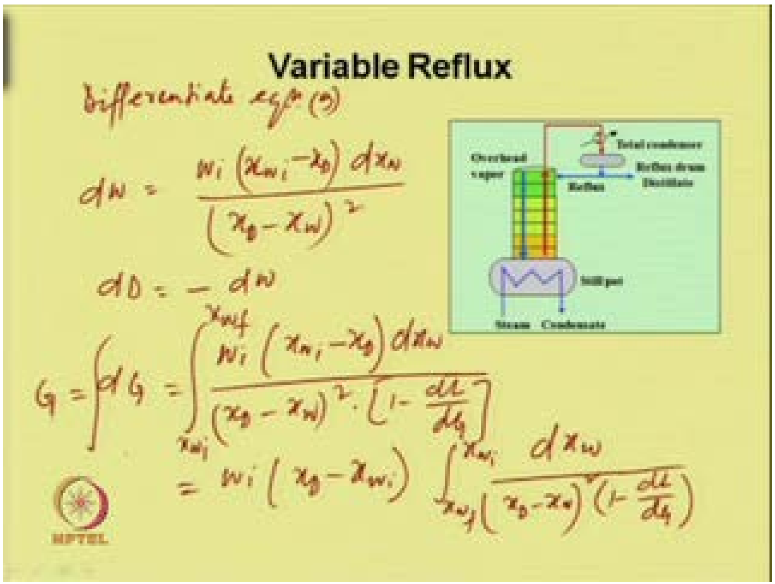

Now, if we differentiate this equations, equation three we will obtain differentiate, we can obtain d w would be equal to W i x w i minus x t d x w divided by x D minus x D square. We know that d D would be equal to minus d W. So, if you substitute this equations in equation two, this one we could obtain d G is equal to W i x w i minus x D d x w divided by x D minus x W square into 1 minus d L by d G. If we want to calculate the total gas flow rate or amount generated, we can write is G integral x w i to x w f it will be W i into x D minus x w i into integral x w f x w i d x w divided by x D minus x w square into 1 minus d L by d G.

Now, area under the curve, we can obtain if we know the values of x D and x w as well as the slope, and then we can calculate the slope of the lines then we can calculate the values of g. Integral can be obtain graphically like we did before and then we can calculate the vapor which is generated.

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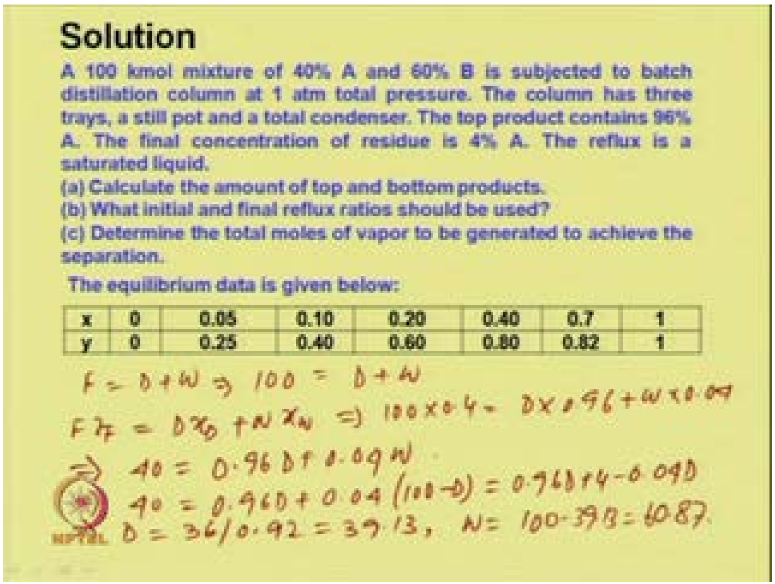

Let us take an example a 100 kilo mole mixture of 40 percent A and 60 percent B is subjected to batch distillation column at one atmosphere total pressure. The column has three trays, a still pot and a total condenser. The top product which contains 96 percent A which is fixed that is x D is fixed at 0.96. The final concentration of the residue is percent A. The reflux is saturated liquid calculate the amount of top and bottom top of to be generated to achieve the separation the equilibrium data are given below.

So, this is the equilibrium data which is given let us do the total material balance that is F is D plus W which is 100 would be D plus W component balance if we do F Z F would be D x D plus W x w. So, you can write 100 into 0.4 would be equal to D into 0.96 plus w into 0.04 then we can write 40 would be equal to 0.96 D plus 0.04 W.

Now, we can substitute D from here and we can write 40 would be equal to 0.96 D plus if we substitute W from here. So, it will be 0.04 into 100 minus D. So, this would be equal to 0.96 D plus 4 minus 0.04 D. So, d would be 36 divided by 0.92 and which is equal to 39.13. So, W also we can calculate W would be 100 minus 39.13 which is equal to 60.87.

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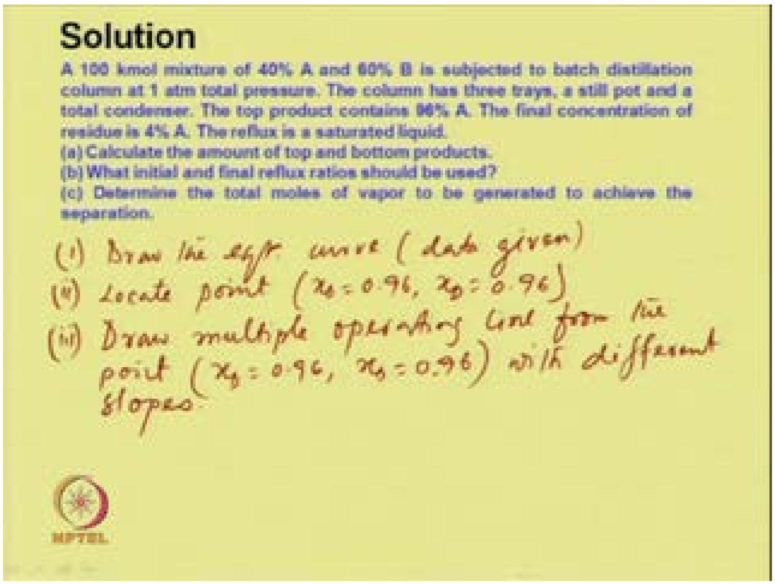

Now, draw the equilibrium line the data is given. Second will locate point x D which is 0.96. From this since the x D is constant the slop of the particular line will change. So, we will draw from starting from this point, we will draw different operating lines, draw multiple operating line from the point x D is equal to 0.96 x D is equal to 0.96.

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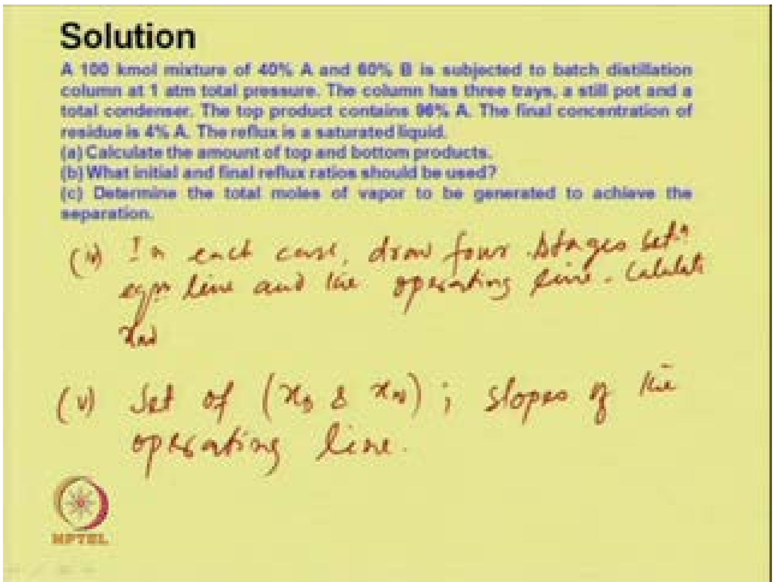

So, from this point draw multiple operating lines with different slopes, and then what we have to do in each case each case draw four stages between equilibrium line and the operating line. And then calculate calculate x w then we will have set of x D and x w. Since, we have x D and x w and also we have slopes of the operating line.

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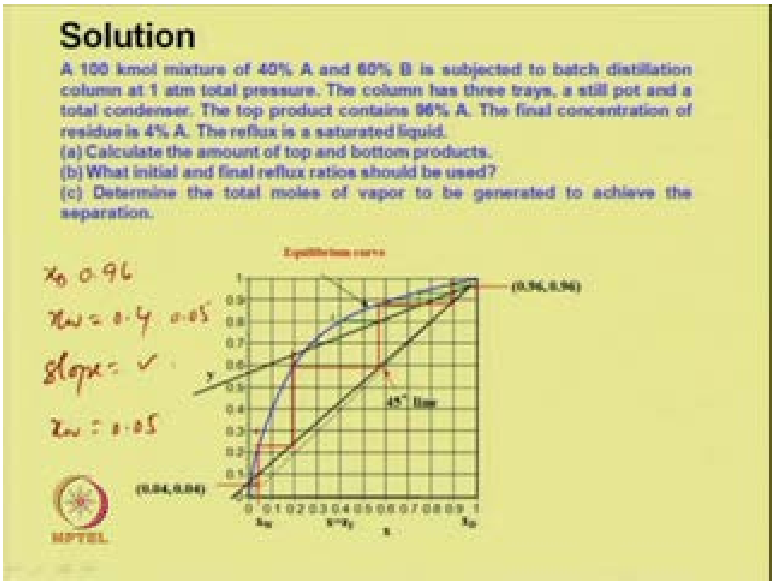

There are two operating line which is shown over here we start at 0.96. And we draw the four stages and the point which is coming 0.96, and we can obtain x D and we could obtain x w with four stages each 0.4. And we can calculate the slope of this operating line slope, also we can calculate for this which is over here. So, slope is known. Similarly, another operating line which is over here x w is 0.05 and slope we can calculate from this operating line. So, that we have a set of x w and we have a slope for each case.

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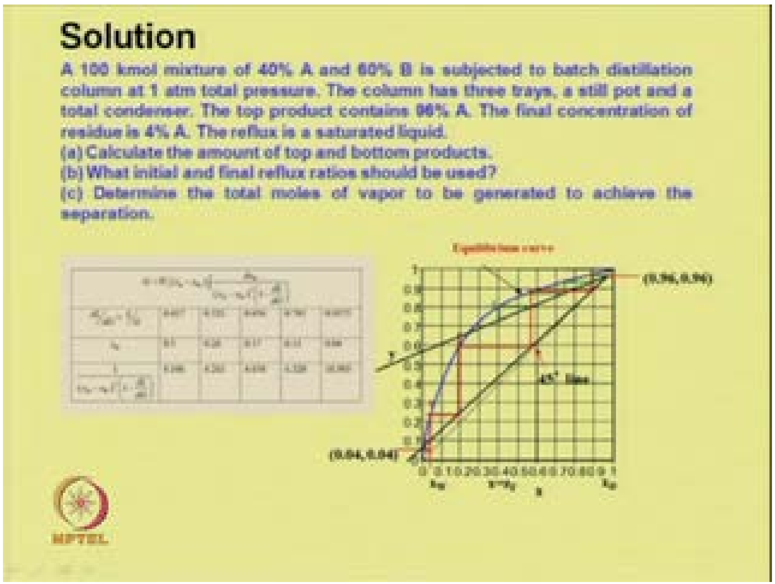

Let us see the table. The first one has slope of 0.417 x w is 0.5, so we could able to calculate this one. Similarly, for the second we have operated 0.521. So, we have a set of data with these we can plot this 1 by x D minus x w square into 1 minus d l by d g verses x w. So, we can calculate the area under the curve for this integral.

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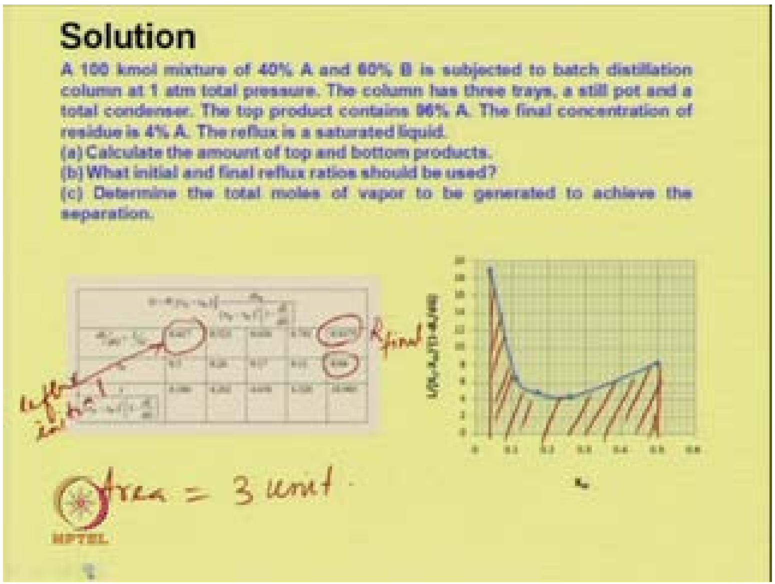

So, the area under the curve for this integral is this, so this is the area is around 3. Now, area is known to us, then the initial reflux which could be used calculate the amount of top and bottom products we have already calculated. What initial and final reflux ratio should be used, the initial and final reflux ratio which is given over here initial is corresponding to 0.5, it is 0.417; and final corresponding to 0.04, it is 0.39. So, it is reflux ratio final, and this is reflux ratio initial. The area under the curve is 3 units.

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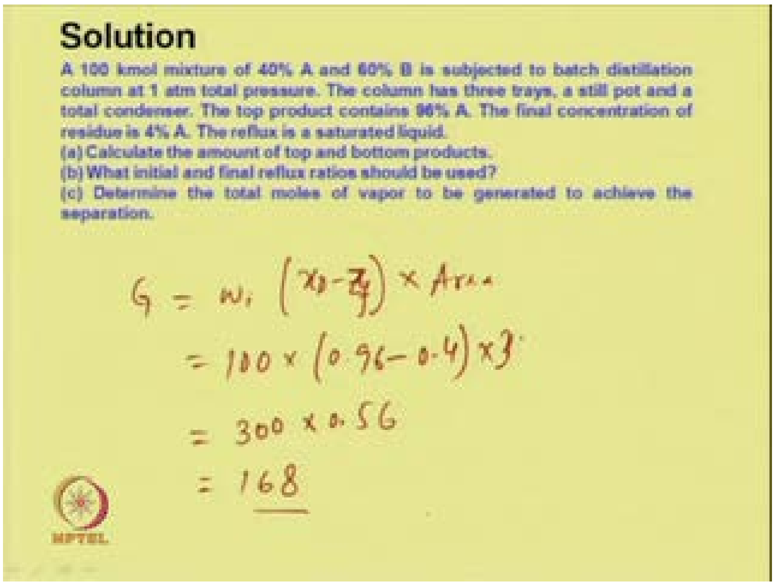

So, we can calculate G which is equals to W i x D minus Z f into area under the curve, so which is equal to 100 multiplied by 0.96 minus 0.4 into is 3 unit. So, it would be equal to 300 multiplied by 0.56 which is equal to 168. So, this way we can determine the total moles of the vapor which is generated to achieve this separation, and the initial and final reflux ratio and the amount of top and bottom products.

Thank you.