Mass Transfer Operations I
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Module - 5
Distillation
Lecture - 9
Fractional Distillation: Multiple Feeds and Side Stream

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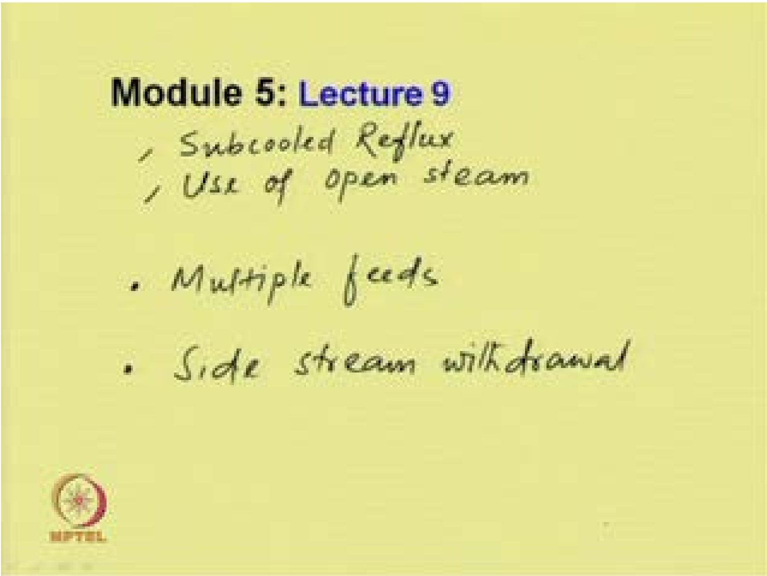

Welcome to the ninth lecture of module five, which we are discussing on distillation. In our previous lecture, we have considered how to handle the subcooled reflux, subcooled reflux, and second thing we have considered use of open steam. In this lecture we will primarily focus on how to handle the multiple feeds, multiple feeds, and second thing if there is a side stream withdrawal, side stream withdrawal. We will first consider multiple feeds problem, and then we will come to the side stream withdrawal problem.

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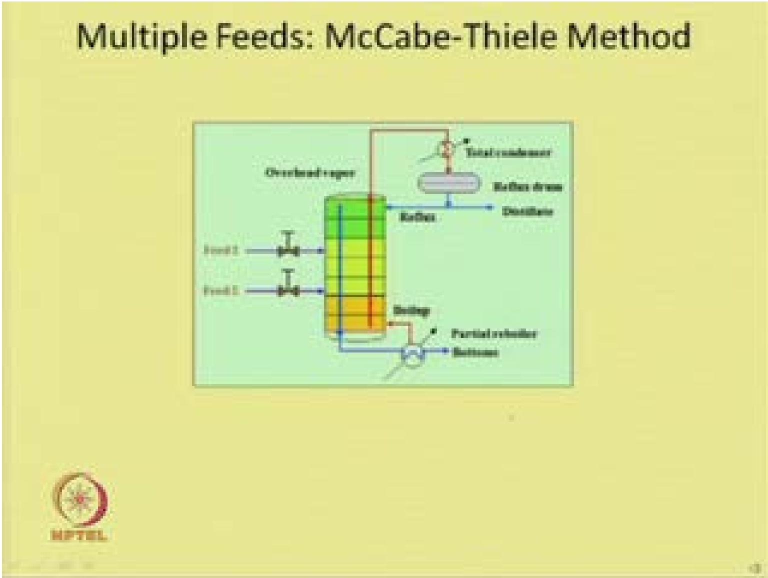

Let us consider multiple feed problems, and we can solve it similarly, like McCabe-Thiele methods. So, this is a distillation column where two feeds are introduced at two different trays, feed one and feed two should have the different compositions, and then two feeds we can handle in the same fractionators.

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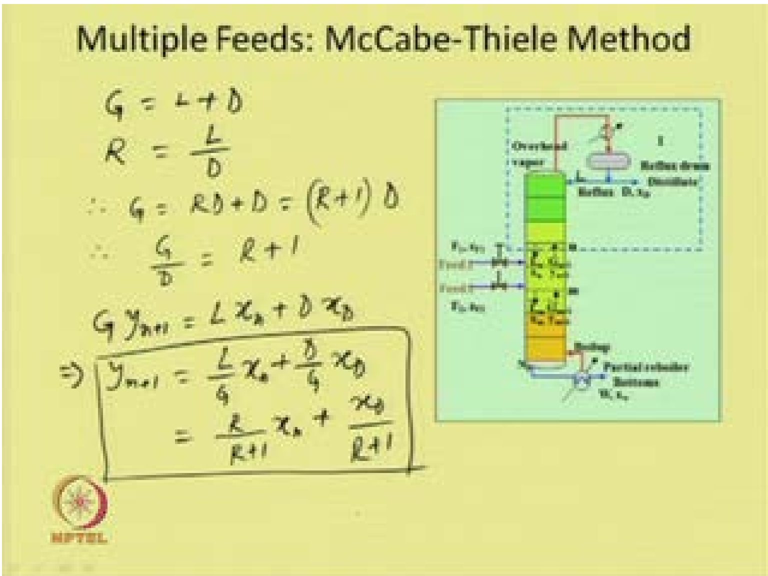

Let us see how to handle this problem, so we will do the material balance for each components and the mass balance. There are primarily three sections: section one above the feed tray, and then the second section which includes the feed one, and then stripping section; section one which represents the enriching section, section two which is taken into account the feed one, and section three is for the stripping section. Let us do the material balance for section one. If we considered a small envelop, considering the reflux drum, and distillate, and the reflux, the material balance over this we can write G is equal to, if this is L then would be L plus D, and if we define the reflux ratio which is R is equal to L by D, so that we can write G is equal to R D plus D is equal to R plus 1 into D; therefore, we can write G by D would be equal to R plus 1.

Now, if we do the material balance for particular components, if we consider envelop one, then we can write G y n plus 1 would be equal to L x n plus D x D, and from this we can write y n plus 1 would be equal to L by G x n plus D by G x D, is equal to R by R plus 1 x n plus x D by R plus 1, this is already we have discussed. This is the equations of the operating line in the enriching section or rectifying section, where the slope of the operating line is R by R plus 1, and intercept is x D by R plus 1.

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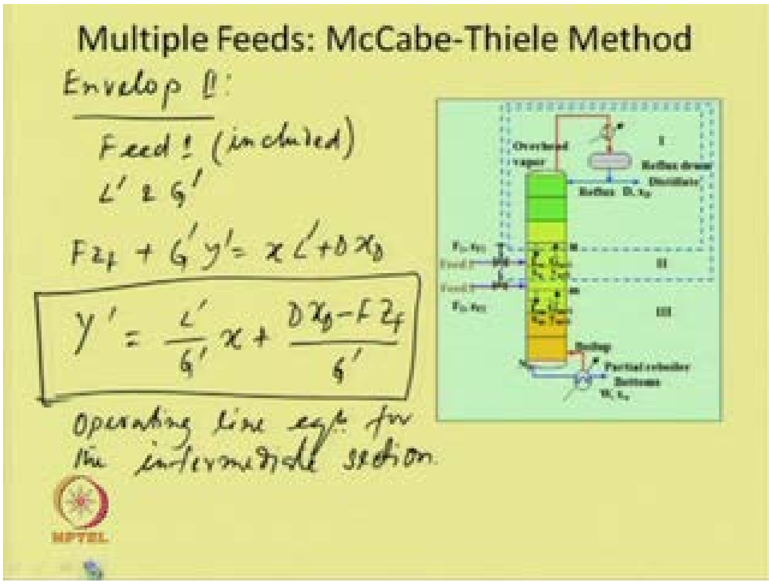

If we consider envelop two, it incorporates the feed one. Then we can calculate L dash and G dash from the vapor and liquid compositions which is from the fluorides of the liquids and gas in each tray. Now, if we do the overall material balance, it would be F z F plus G dash y dash, it would be equal to x L dash plus D x D; so we can write, Y dash would be equal to L dash by G dash into x plus D x D minus F z F divided by G dash.

This is the operating line for the intermediate section, operating line equations for the intermediate section.

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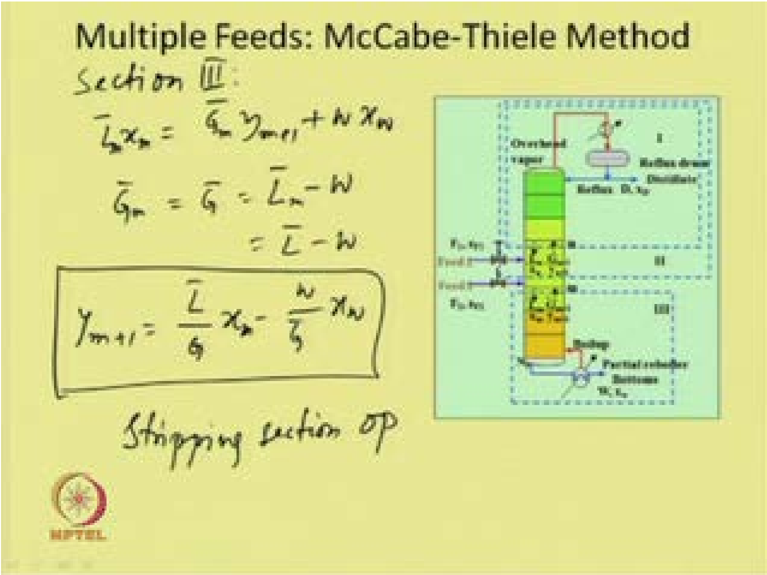

Now, we will consider the stripping section, as we did earlier, if we do the martial balance, it would be L n bar x n is equal to G m bar Y m plus 1 plus W X W; and if we put G m bar is equal to G bar is equal to L m bar minus W is equal to L bar minus W, then Y m plus 1 would be equal to L bar by G x m minus W by G bar X W. This is the equation of the operating line we have discussed earlier in the stripping section, operating line, and this is for section three.

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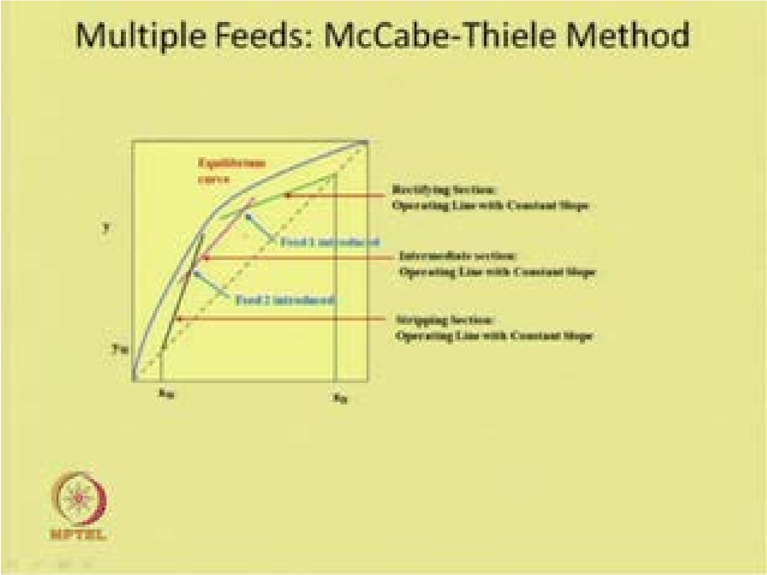

For a given reflux ratio, we can plot the operating line, the rectifying section, and then this is for stripping section, and this for intermediate section. Now, this intermediate section operating line coincides at two different feed plate locations, and that will be decided from the feed line.

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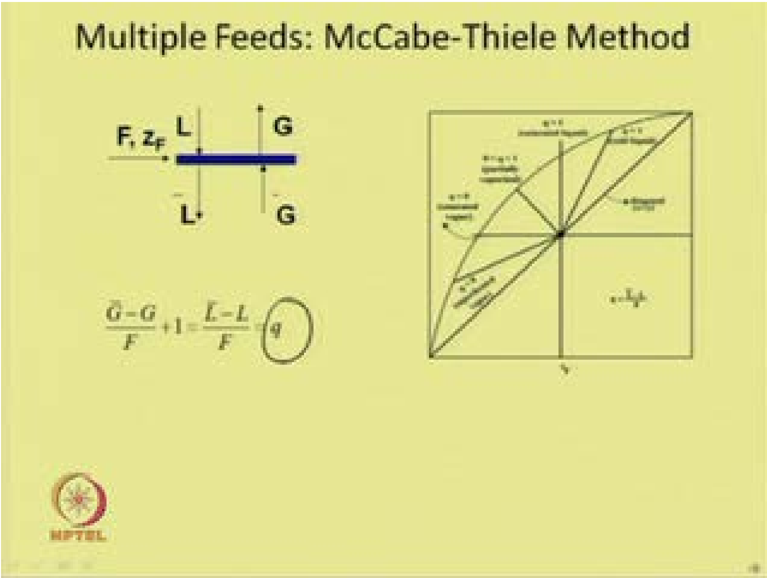

Suppose, this is the feed plate, and we know the feed flow rate and compositions, and then we can write the slope of the q line, which we discussed earlier; this is slope of q line, and which based on that you can see where the feed line will intersect.

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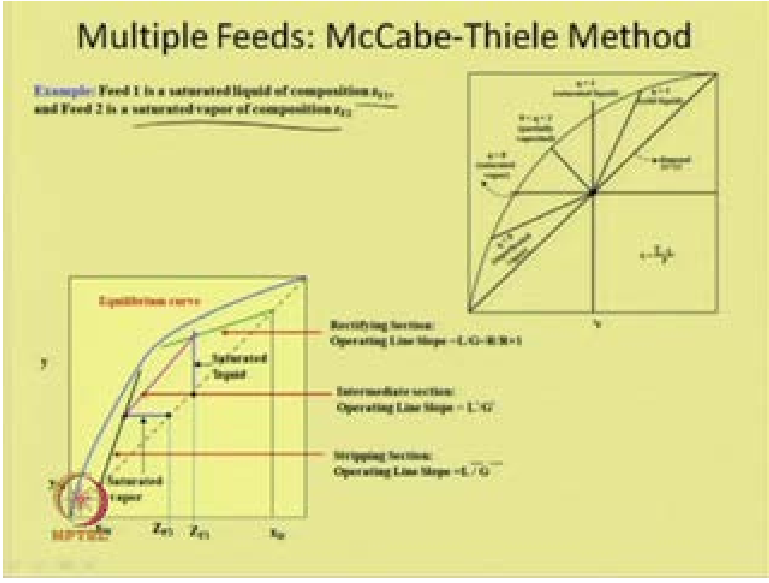

Consider two feeds. Feed one, which is a saturated liquid of composition Z F 1, and feed two is a saturated vapor of composition Z F 2. So, for saturated vapor at a particular feed the q line slope would be 0, and for the saturated liquid q would be 1. If we can draw the operating line for the rectifying section, this is Z F 1 which has compositions Z F 1, and a saturated liquid if we plot with a slope of 1 then it will intersect the stripping section line and the starting point of the operating line in the intermediate section. Similarly, it would intersect the other feed points between stripping section and slope of the q line of other feed, feed two, Z F 2, which is a saturated vapor, which intersects over here.

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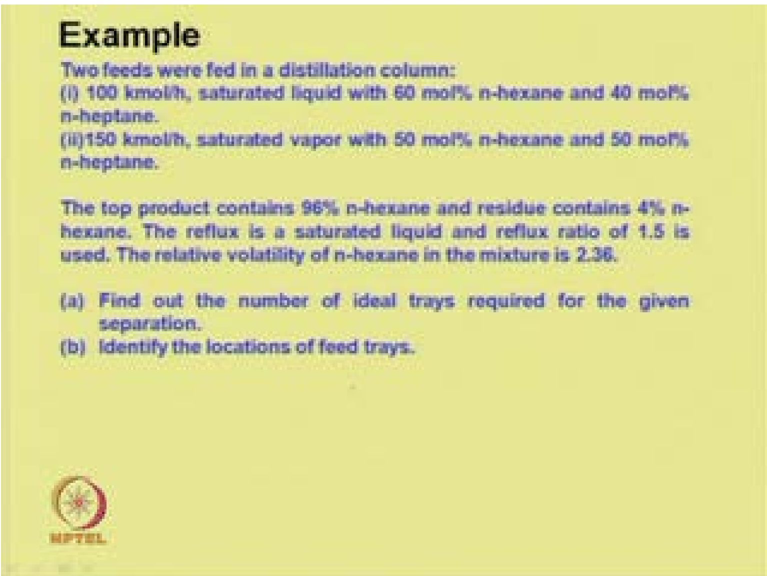

Let us take an example. Two feeds were fed in a distillation column, feed one which as a 100 kilo mol per hour, saturated liquid with 60 mole percent n-hexane and 40 mol percent in mol n-hetpane; and feed two which is 150 kilomol per hour, saturated vapor with 50 mol percent n-hexane and 50 mol percent n-hetpane. The top product contains 96 percent n-hexane and residue contains 4 percent n-hexane. The reflex is a saturated liquid and the reflex ratio of 1.5 is used. The relative volatility of n-hexane in the mixture is 2.36. Find out the number ideals trays of required for the given separation, and identify the locations of feed trays.

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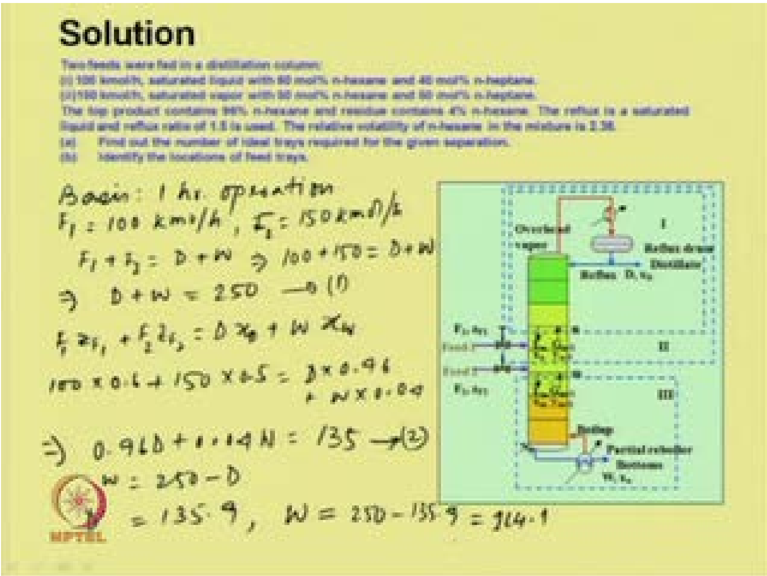

Let us take a basis of 1 hour operation. So F 1 is given 100 k mol per hour and F 2 is given which is 150 k mol per hour, if we do the total material balance then F 1 plus F 2 would be D plus W, which we can write 100 plus 150 would be equal to D plus W; we can write D plus W would be equal to 250, suppose this equation one.

Now, if we do the balance on the n-hexane we can write F 1 Z F 1 plus F F 1 and F 2 Z F 2 would be equal to D x D plus W x W, we can write 100 into 0.6 plus 150 into 0.5, would be equal to D into 0.96, plus W into 0.04, this would be equal to 0.96 D plus 0.04 W would be equal to 135, say this is equation two. And if we substitute from equation one, then we can write W is equal to 250 minus D; and if we substitute this in equation one, D would be equal to 135.9, and if we substitute this in equation one W would be

250 minus 135.9, which would be equal to 114.1. So the distillate and the, but on flow rate we could able to calculate with total material balance.

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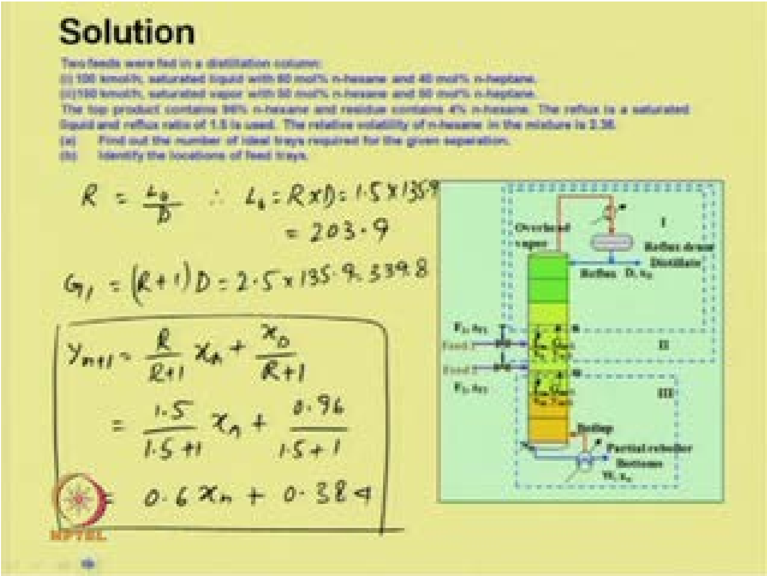

Let us consider the rectifying section, section one over here, so the reflex is saturated liquid, so we can write R is equal to L naught by D, and therefore, we can write L naught would be R into D which would be equal to 1.5 into 135.9, which is equal 203.9. And G 1, gas flow rate would be R plus 1 into D, which is 2.5 into 135.9, which is equal to 339.8. So, the equations of the operating line, as we have derived earlier, Y n plus 1 would be R by R plus 1, x n plus x D by R plus 1, so this would be equal to 1.5 divided by 1.5 plus 1 x n, plus x D is 0.96 divided by 1.5 plus 1, so we could write 0.6 x n plus 0.384. This is the equations of the operating line in the stripping section.

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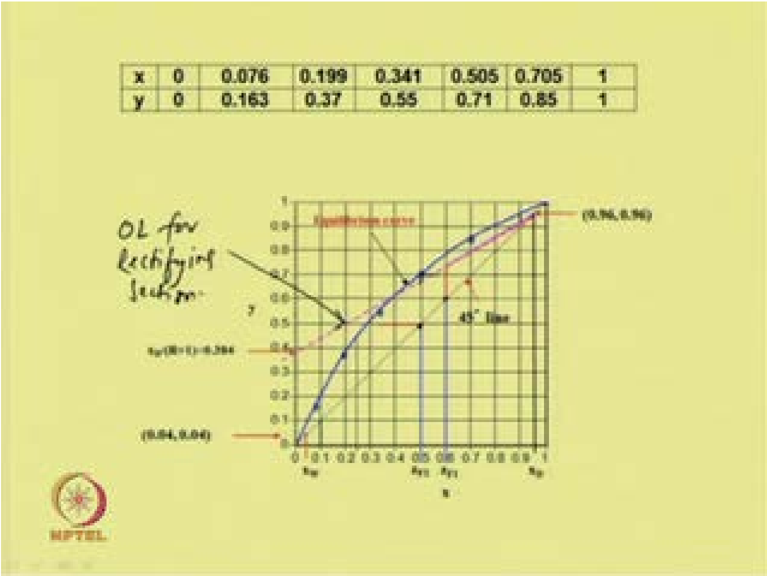

We know the equilibrium relations which is given, use the relative volatility equations, and we can calculate the equilibrium data. So, x and y value we calculated like this, and we can plot the equilibrium line, and we locate the feed points over here that is Z F 1 which is 60 percent and 50 percent is for Z F 2, x W is given and which is at 0.04, which is over here; and then the equilibrium data are floated over here which is shown in the blue line, the equilibrium curve. As we have calculated, intersect the x G by R plus 1 which is 0.384. So, from this intersect, and with the x D, and the x D which is 96 percent is given over here, we can plot the operating line, so this is the operating line for the rectifying section, for rectifying section.

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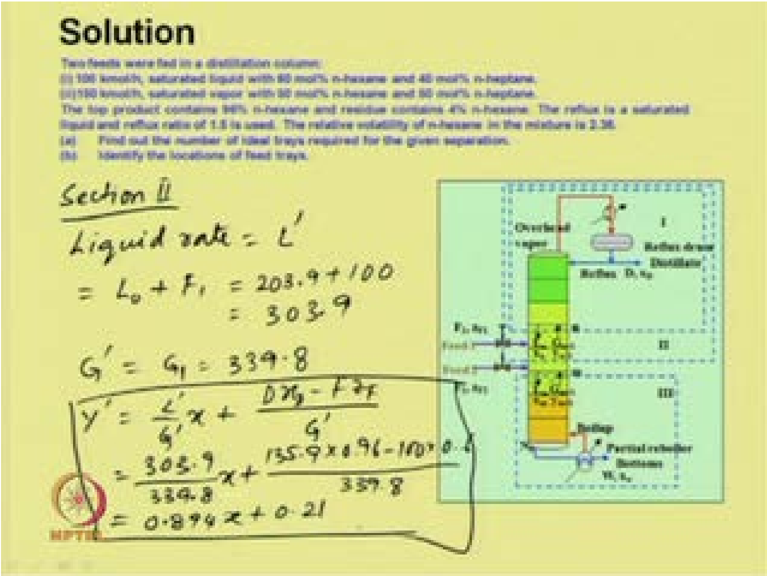

Now, for section two, the liquid rate which is equal to L dash would be equal to L naught plus F 1. Since, the feed one is a saturated liquid, the feed flow rate in section two would be enhanced by F 1, so the total flow rate would be 203.9 plus 100 which is equal to 303.9. And gas rate which would remain same, G dash would be G 1 that is section one which is 339.8. So, the operating line equations, Y dash would be equal to L dash by G dash, x plus D x D minus F Z F by G dash, if we substitute, it would be 303.9 divided by 339.8 x plus 135.9 into 0.96 minus 100 into 0.6 divided by 339.8, which would be equal to 0.894 x plus 0.21. This is operating line equations for the intermediate section.

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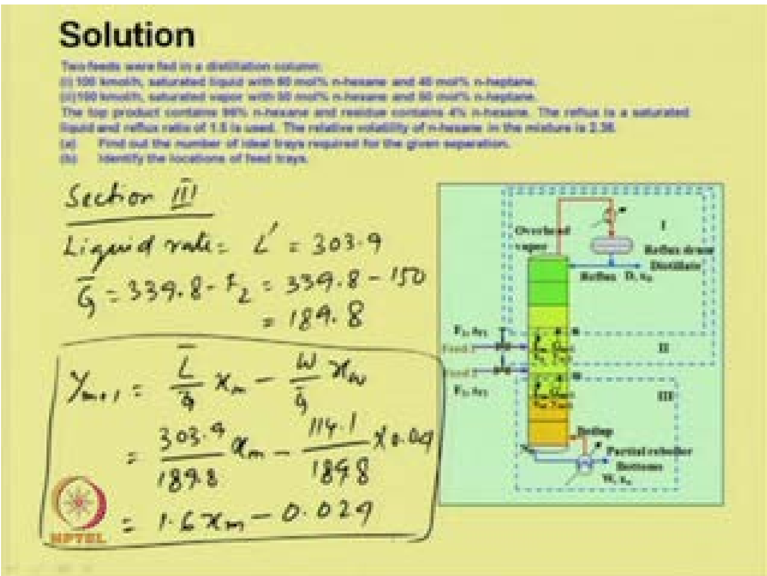

Now, let us consider section three that is the stripping section, where the liquid rate, rate remain same which is L dash, because the feed two is a saturated vapor, and G bar would be equal to 339.8 minus F 2 which equal to 339.8 minus 150, which is around 189.8. So, we can write Y m plus 1 would be L bar by G x m minus W by G bar into x W, which is equal to 303.9 divided by 189.8 x m minus 114.1 divided by 189.8 into 0.04, which would be 1.6 x m minus 0.024. This is the operating line equations in the stripping section.

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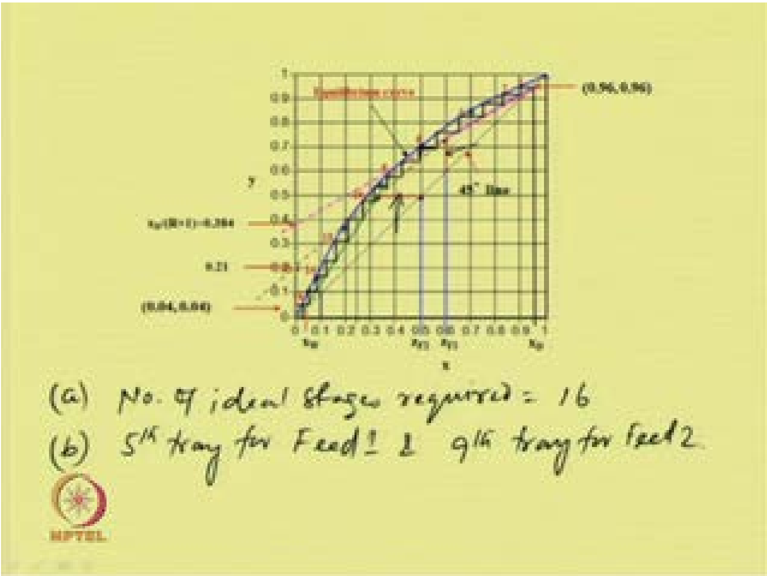

With this, we can now plot the equilibrium, we know how to plot the equilibrium line, and we know the intersect for the intermediate operating line, so this is the intersection, and the feed is a saturated liquid which intersect over here, so from this point we can draw the operating line of the intermediate section, and we know the feed conditions over here, at Z F 2, and is a saturated vapor the q line equations is this, so these are the q line, this is q line, and this is q line for feed two, it intersect over here, we can now join the operating line equations for the stripping section.

Now, we can do the cheer case construction to obtain the number of ideal plat requires, and the sifting occurs at the inter sections point from the intermediate operating line to the stripping section as well as intermediate operating line and rectifying section operating line. We can see number of ideal stages require is equal to 16, and the first cross over occurs at plate number five 5 th tray for feed one, and 9 th tray for feed two, so this is the feed plate locations.

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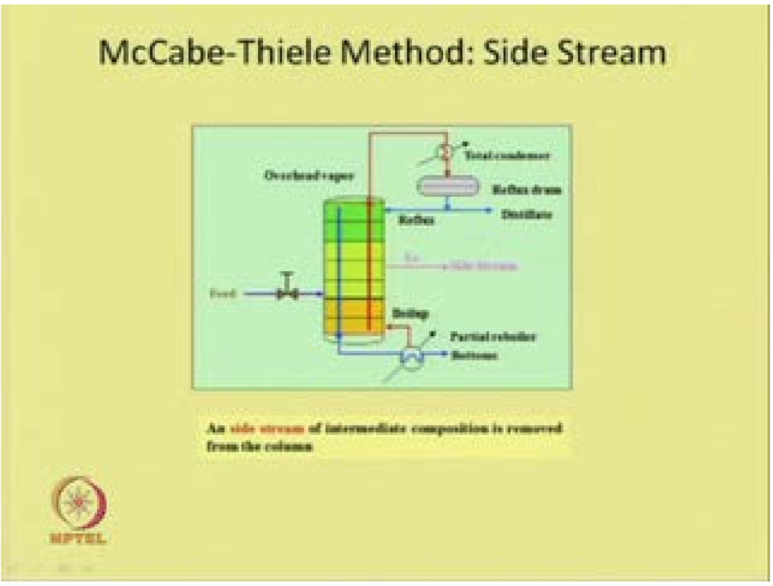

Let us consider another important thing which is the side stream, we have a single feed column, and we have intermediate product withdrawal, at a certain plats, there is a side streams withdrawal.

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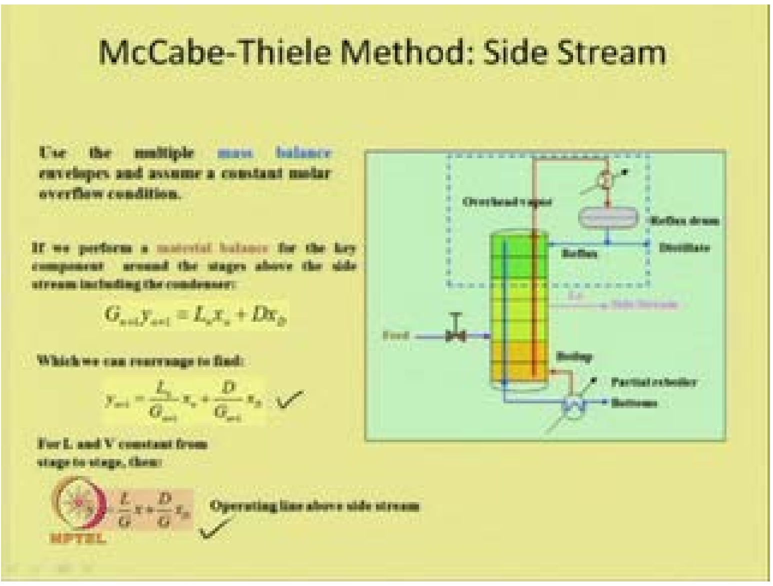

We can use the multiple mass balance envelopes, as we did before. First envelop we will consider without considering the side stream. So, we will get the operating line for the rectifying section, this is the operating line for the rectifying section.

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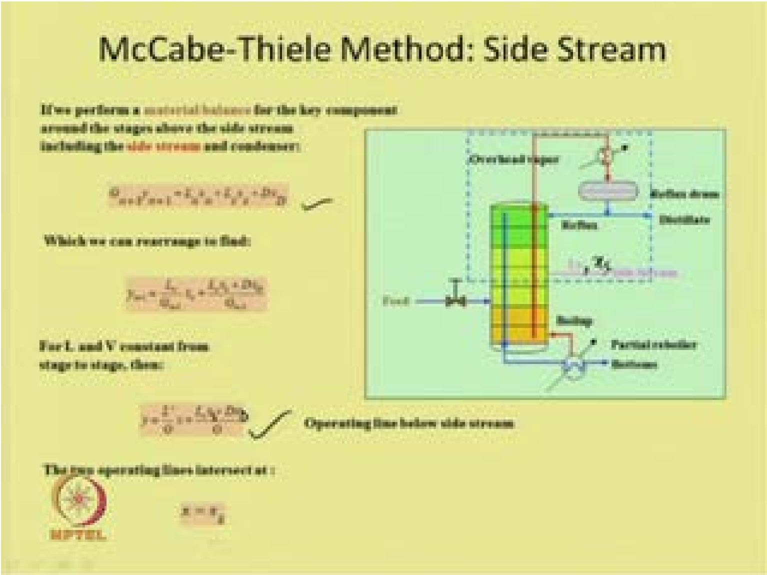

Now, if we include the side stream and do the material balance for the key component, we can write G n plus 1 Y n plus 1, would be equal to L n x n plus L s x s plus D x D, this is the material balance equation, and if we rearrange it would be Y n plus 1 would be L n by G n plus 1 x n plus L s x s plus D x D divided by G n plus 1. So, L s is the rate of side stream which is withdrawal, and its composition is x s, this would be x s and x D. This is the equations of the operating line considering the side stream, and it would intersect both the operating line of the enriching section, and the operating line considering the side stream will intersect at a point x is equal to x s.

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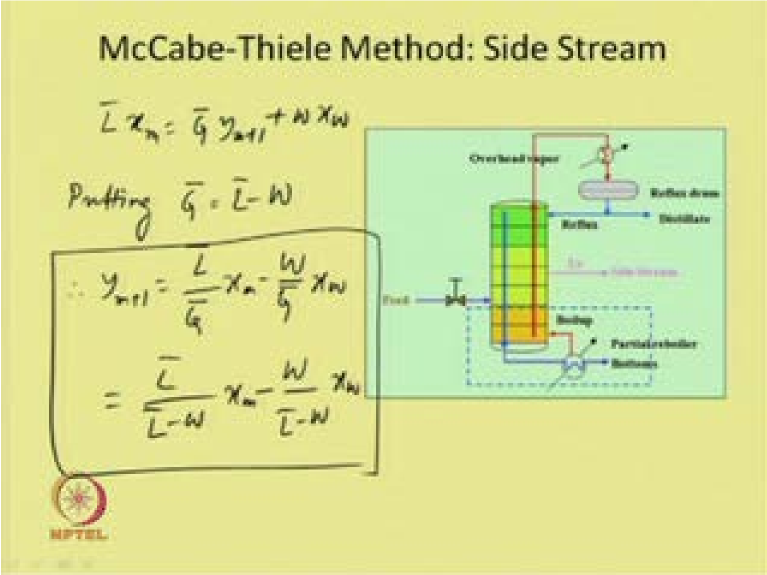

Now, if we do the material balance for the stripping section, L bar x m would be G bar y m plus 1 plus W X W, and if we rearrange this, we could write putting G bar would be L bar minus W. Therefore, we can write y m plus 1 would be L bar by G bar X m minus W by G bar x w, which is equal to L bar, L bar minus w x m minus W by L bar minus W X W, so this operating line equations for the stripping section.

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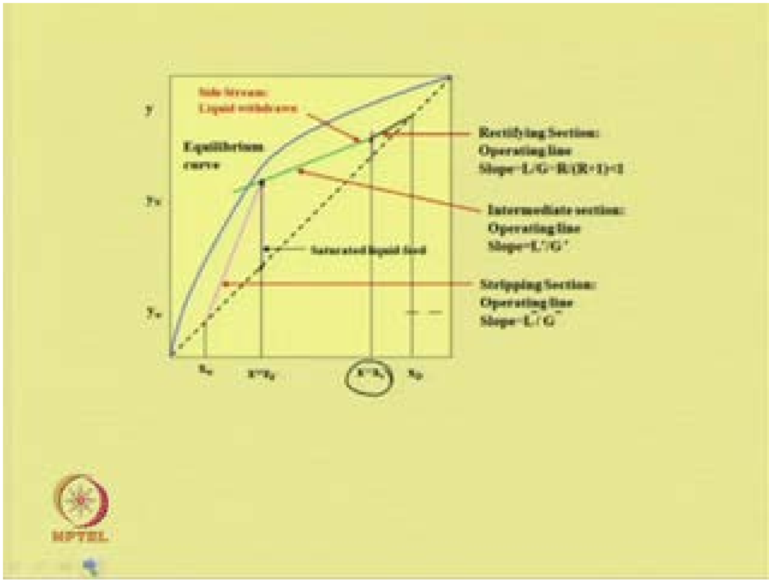

And, we can plot the operating line, this is the operating line for the stripping section, and this is operating line for the intermediate section, where it intersects at x is equal to x s at this locations, and then this is the feed conditions Z F, and it intersects at this location, since it is a saturated feed. For the determinations of the minimum reflex ratio for this is type of column is bit tricky, because the peach point may occur at the inter section of the feed line or the side line, and the equilibrium line; if the equilibrium curve as any unusual curvature, a peach point may be found out by drawing an operating line that touches the equilibrium curve.

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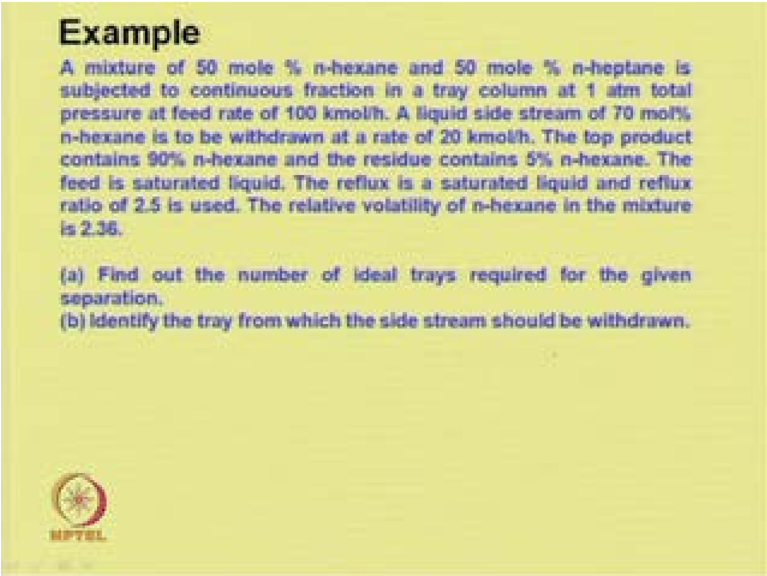

Now, let us take an example of the this type of problem of side stream withdrawal, equimolar compositions of n-hexane, n-heptane is subjected to a fractional distillation at 1 atmosphere pressure and with a feed flow rate of 100 kilo mol per hour. A liquid side stream of 70 mol percent of n-hexane is to be withdrawn at a rate of 20 kilo mol per hour. The top product contains 90 percent n-hexane and the residue contains 5 percent n-hexane. The feed is saturated liquid. The reflex is a saturated liquid and reflex ratio of 2.5 is used. The relative volatility of n-hexane in the mixture is 2.36. Find out the number of ideal trays required for the given separation, and identify the tray from which the side stream should be withdrawn.

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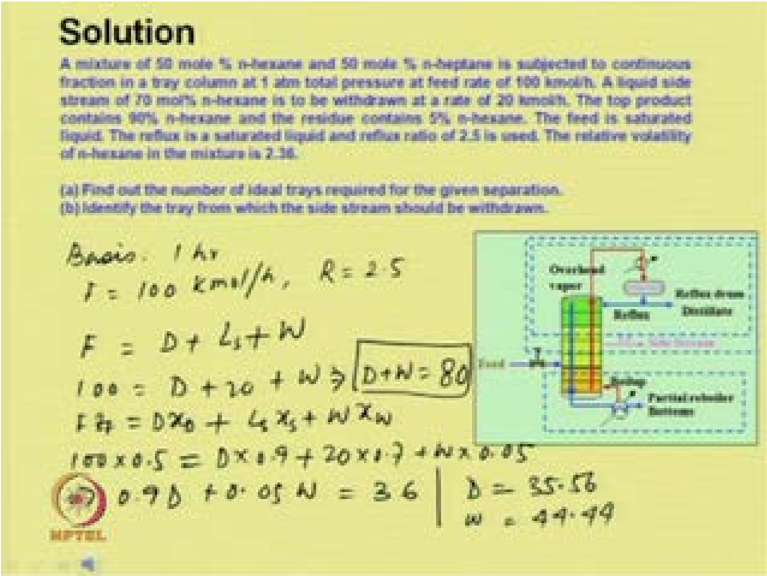

Let us consider, this is the column where we have three sections, one without side stream, and anther without considering side steam, the other one is stripping section. We can write basis 1 hour, operations and feed is given 100 k mol per hour, and reflex ratio is 2.5 is given; then the equilibrium data is given, we can plot the equilibrium data, overall material balance if we do, then we will have F would be equal to D plot side steam we can write, L s plus W, this we can write 100 would be equal to D plus 20 plus W, so this would be D plus W is equal to 80.

Now, if we do the material balance F Z F would be equal to D x D plus L s x s plus W x W 100 into 0.5, would be equal to D into 0.9 plus 20 into 0.7 plus W into 0.05, so from this we can calculate, 0.9 D plus 0.05 W would be 36; and, substituting the valves from this D plus W is equal to 80 in this equation, we can calculate D is equal to 35.56, and W would be equal to 44.44.

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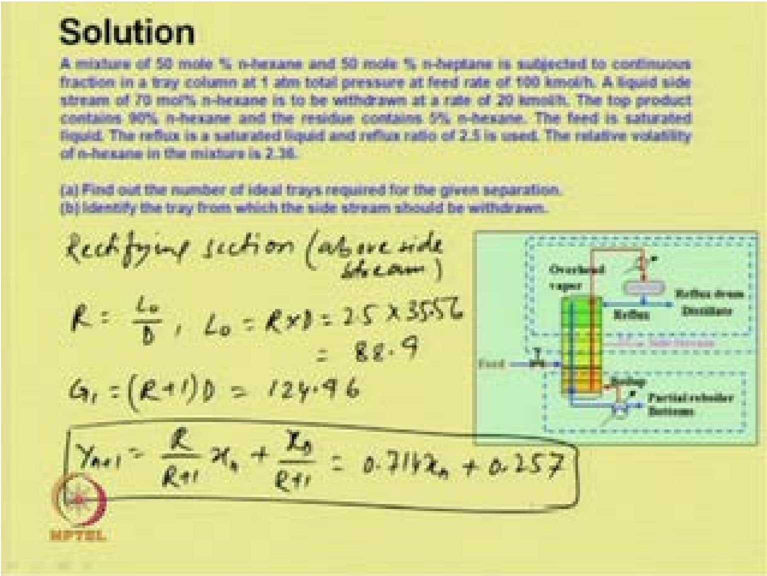

Now, let us consider the rectifying section, rectifying section above side stream, above side stream, R is equal to L naught by D, so L naught would be R into D which is equal to 2.5 into 35.56, and it should be 88.9; and G 1 would R plus 1 into D, and which is equal to 124.46. Now equations of the operating line, Y n plus 1 would be R by R plus 1 x n plus x D by R plus 1 which is equal to 0.714 x n plus 0.257, this is the equations of the operating line.

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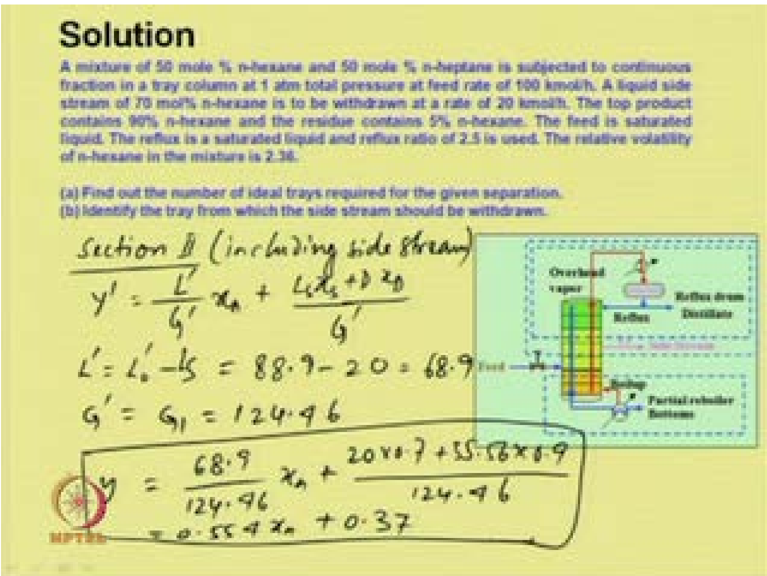

In this rectifying section, now section two, including side stream we have operating line equations, Y dash would be L dash by G dash into x n plus L s X s plus D x D by G dash, so we can write, L dash would be L naught minus L s, because the side stream is withdrawn, so the flow rate in this section would be reduced by L s, so it would be equal to 88.9 minus 20, which is equal to 68.9.

Now, the gas flow rate G dash would be similar to the rectifying section, which is equal to 124.46, and so the operating line equations would be y is equal to 68.9 divided by 124.46 x n plus 20 into 0.7 plus 35.56 into 0.9 divided by 124.46 which would be equal to 0.554 x n plus 0.37, so this is the equations of the operating line or the intermediate section.

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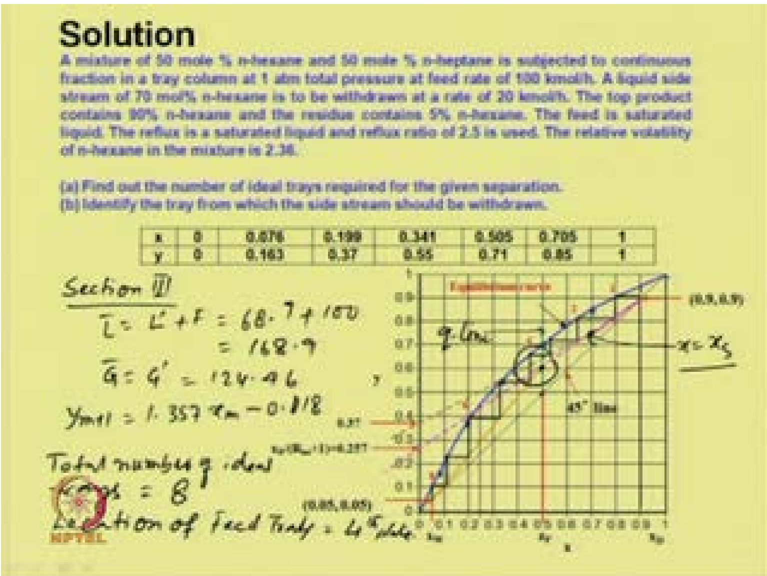

For section three, section three that is stripping section, the liquid flow rate L bar would be L dash plus F which is equal to 68.9 plus 100, which is 168.9; and gas rate is G bar would be G dash which is equal to 124.46, so the equations of the operating line for the stripping sections similar way we can write Y m plus one would-be equal to is coming out to be 1.357 x m minus 0.018.

So, we know the equilibrium data, since the relative volatility of the system is given; from the earlier examples, we can use this equilibrium data, we can plot the equilibrium line; and side stream which is given at a intersection points 0.37, this is over here, so it is for the side stream, and which will intersect at a point over here, so this is the point where x would be x s; and at this point, the slope of the intermediate section line is given, and the intersect is 0.37, and we could plot this equations; and then we know the feed conditions which is 50 percent equimolar, and we plot the q line, this is the q line; and we have the operating line for the stripping section which intersect the q line at this locations; then we can just make the stair case, and we should shift from the intermediate section operating line to the stripping section operating line at the feed plat; this is the locations where the shift from the intermediate section operating line to the stripping section operating line occurs. Total number of ideal trays is equal to 8, and the location of the feed trays is 4th, location of feed tray is 4th, 4th plate.

Thank you.