Mass Transfer Operations-I
Prof. Bishnupada Mandal
Department of Chemical Engineering
Indian Institute of Technology, Guwahati

Distillation
Lecture - 37
The Ponchon-Savarit method - II

Welcome to the twelfth lecture of module 5 on Mass Transfer Operation. In this module we are discussing distillation operations. Before going to this lecture let us have brief recap on our previous lecture.

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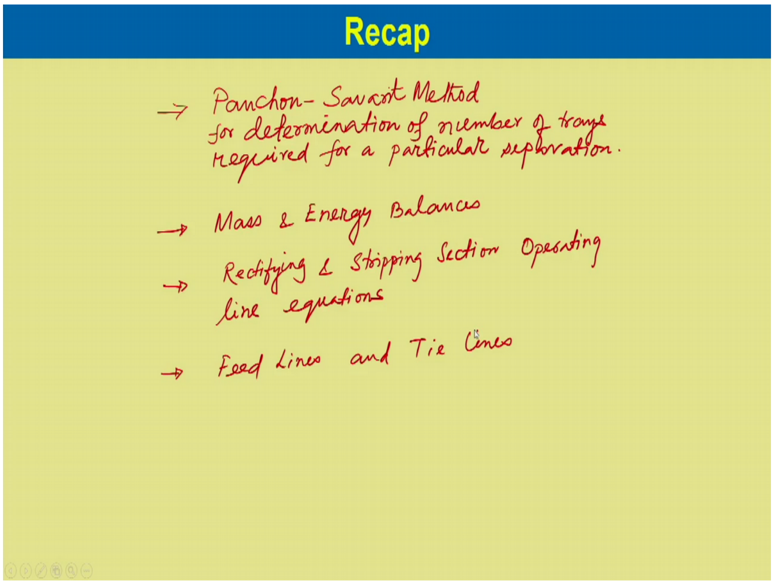

In our previous lecture we have considered Ponchon and Savarit method for the determination of number of plates required for a particular operation.

We have also considered under this, the mass and energy balances. This is for both rectifying and stripping section, and obtained operating line equations. We have also discussed about the feed lines and tie lines.

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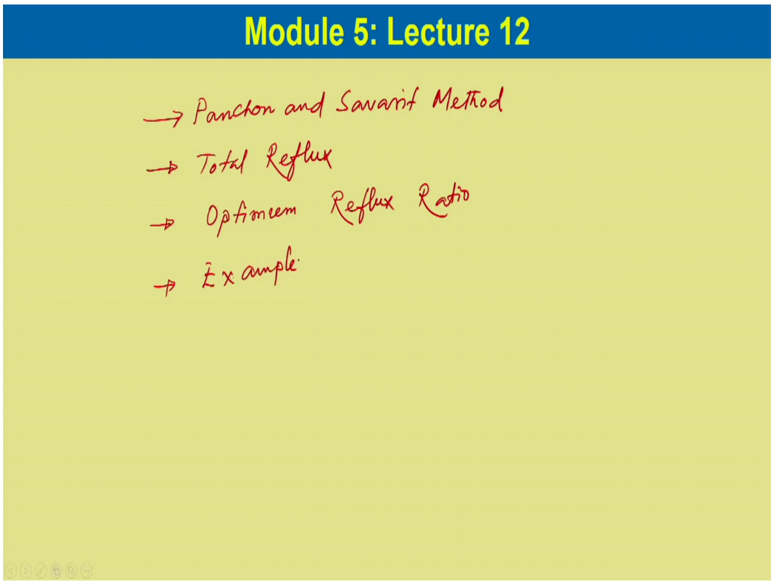

In this lecture, we will continue with the Ponchon and Savarit method. And we will obtain the number of plates requires for a particular operation. And then we will also consider different limiting cases like total reflux. We will also consider the optimum reflux ratio determination. And we will complete with an example.

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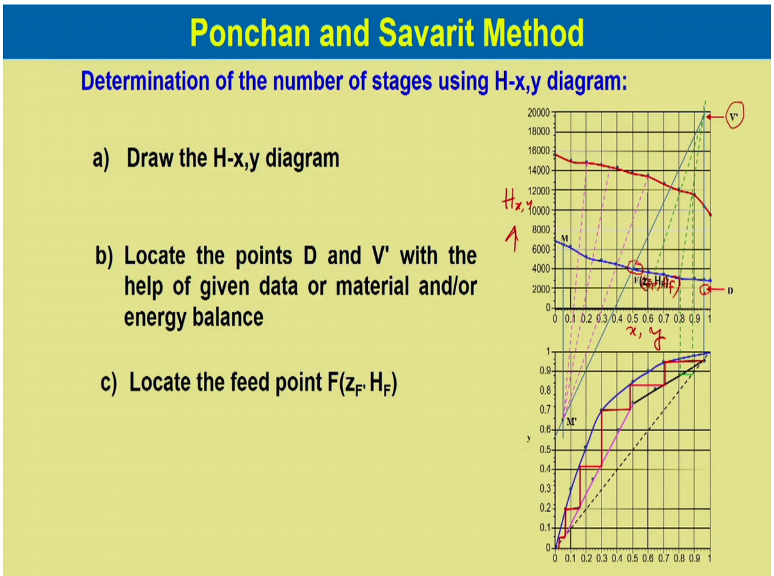

So, let us start with Ponchon and Savarit method for determination of number of stages using H x y diagram. So, to obtain the number of stages using H x y diagram, we need to draw the H x y diagram. So, this is the H x y diagram this is H enthalpy of vapour and the liquid. And this is x y. Then we need to locate point D and V dash with the help of the data or the material and or energy balance. The D is the point it depends on the feed conditions and the distillate conditions.

So, point D each over here, it is given over here. And V dash which we have discussed before is located over here. And this can be obtained from the mass and energy balance equations. Locate point F that is the feed which is over here say point F having the composition Z F H F.

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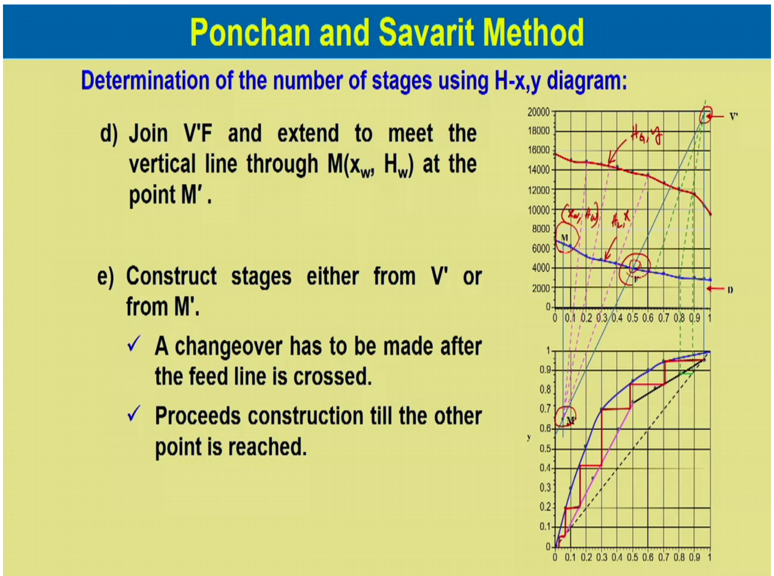

Now, determination of number of stages we have to follow certain steps. We need to join V dash and F. So, these 2 points we need to join V dash and F and extend to meet the vertical line which is coming from this point M which is over here and this V dash F line should extend and intersects with the vertical line coming from M. So, which is M dash and this M is having the composition x W and enthalpy H W. So, this is H G y and this is H L x curve.

Now, we need to construct the stages either from V dash from this side or from M dash. So, these 2 points will consider both the stripping section and the rectifying section. A changeover has to be made after the feed line is crossed. So, this is over here. So, that changeover of the number of plates will happen after this feed point or feed line. Proceeds construction till the other point is reached.

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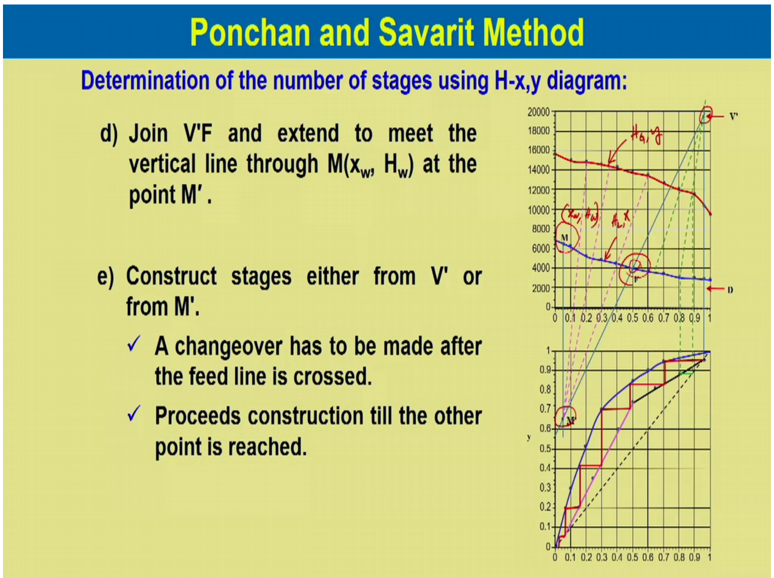

Now, draw the equilibrium curve using the separate axis below the H x y curves with matching scales.

So, you can see over here at the bottom we have drawn the equilibrium curve, so, which is below the H x y diagram, enthalpy concentration diagram. So, it is x y diagram and the equilibrium data we can plot over here. And then we can locate x D and x D and x W and x W x D and x D. We can get over here depending on the conditions given x W and x W which is over here. And this is the point x D and x D depending on the distillate composition.

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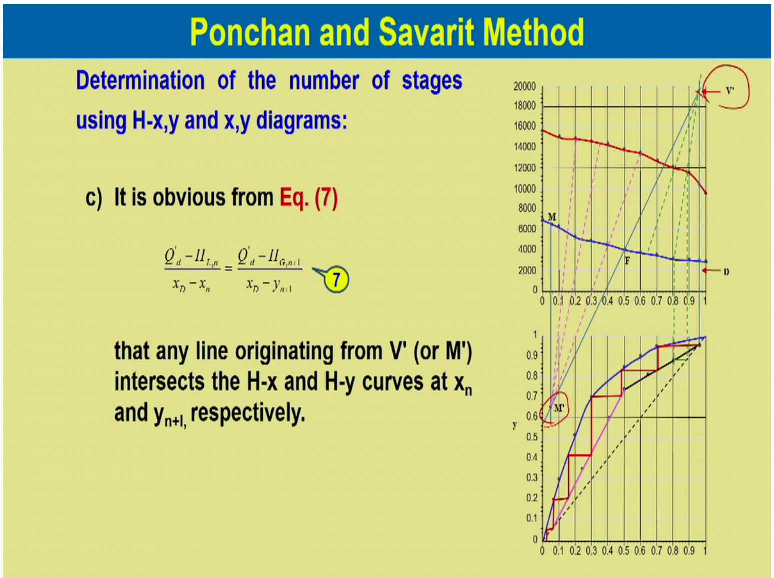

Now, it is obvious from the earlier discussion equation 7 which we have done before in the last lecture, equation 7 which is Q d dash minus H L n divided by x D minus x n is equal to Q d dash minus H G n plus 1 divided by x D minus y n plus 1 that any line originating from V dash or M dash this 2 points intersects the H x and H y curve at x n and y n plus 1 respectively.

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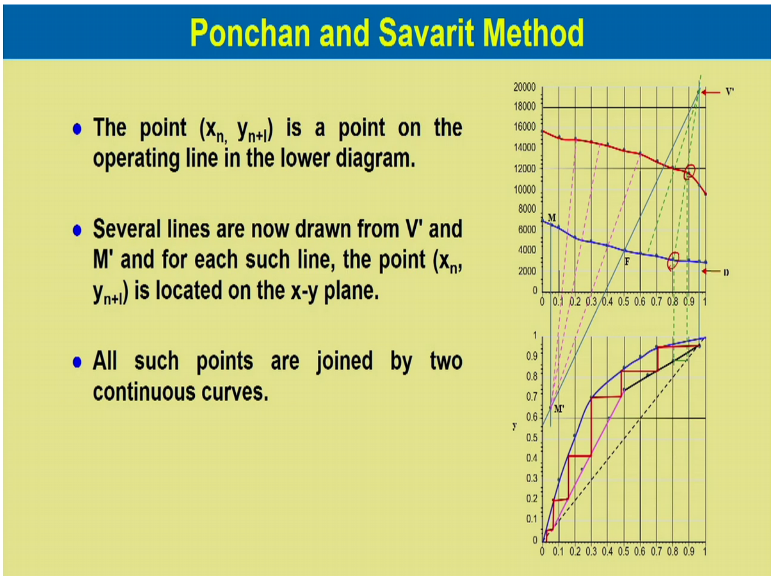

The point x n y n plus 1 is a point on the operating line in the lower diagram. Several lines are now drawn from V dash M dash and for each such line the point x n and y n plus 1 is located on the x y plane. So, you can see over here from this point we can directly come to the 45 degree diagonal. And then we can proceed horizontally, and then we can draw the vertical line from to get the operating line from this point. All such points are joined by 2 continuous curves.

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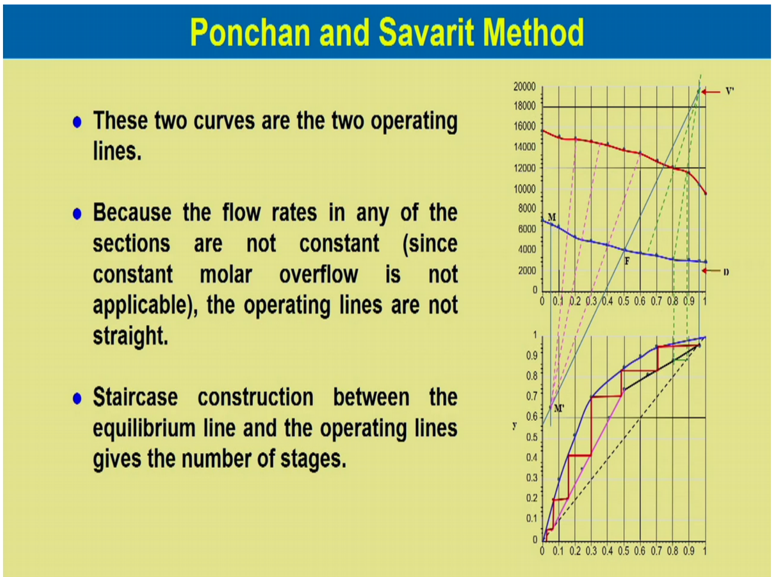

And this 2 curves are the 2 operating lines. So, both rectifying section and the stripping section operating line we can draw using the H x y diagram.

Because the flow rates in any of the sections are not constant, since constant molar overflow is not applicable the operating lines are not straight lines. Although it is shown over here is a straight line depending on the conditions we have taken, but usually if it is not constant molar overflow, then this operating line will be the curve line. So, staircase construction between the equilibrium line and the operating line gives the number of stages as shown over here.

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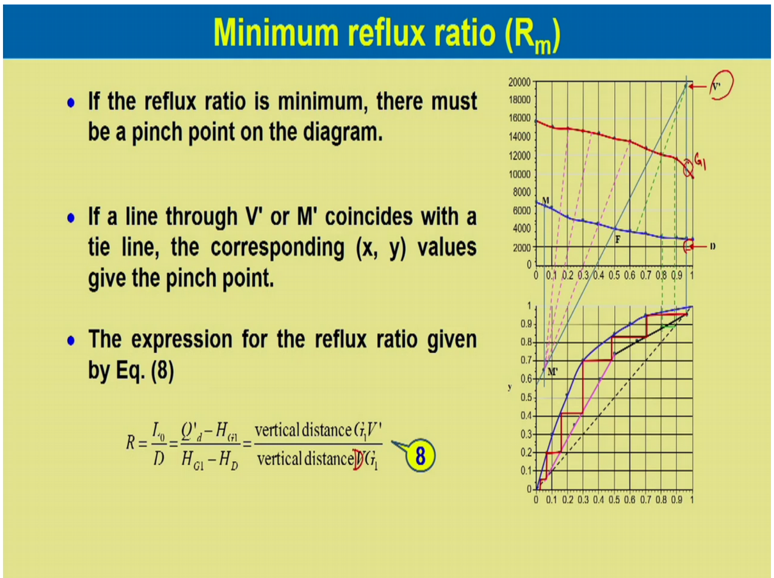

Now, if the reflux ratio is minimum there must be a pinch point on the diagram. If a line through V dash or M dash coincides with a tie line the corresponding x y values give the pinch point. The expression for the reflux ratio given earlier which we have discussed is R is equal to L naught by D would be equal to Q d dash minus H G 1 divided by H G 1 minus HD is equal to vertical distance from G 1 V dash G 1 is over here and V dash is over here divided by the vertical distance this is (( )); D G 1. So, from this point to G 1, equation 8 indicates that the smaller the distance G 1 V dash from here to this or nearer the point V dash in the concentration axis the smaller is the reflux ratio.

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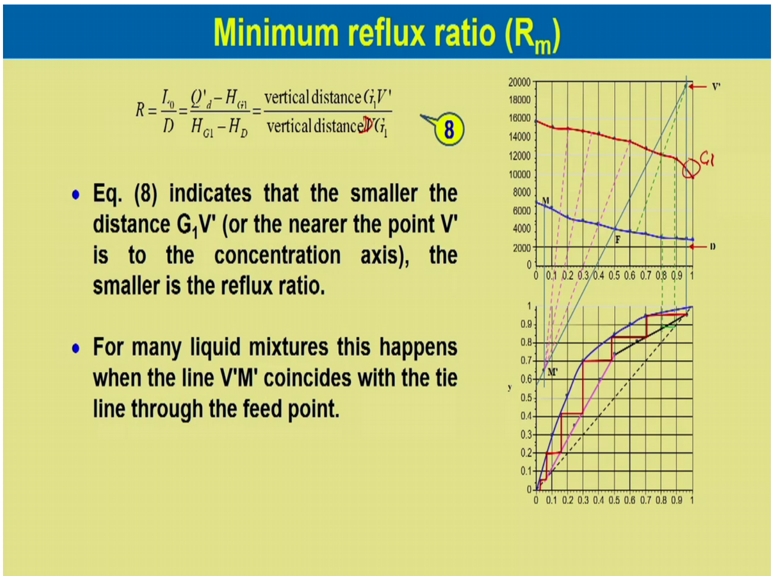

So, as this will come closer to this G 1 or this distance as small as possible the reflux ratio will be small. For many liquid mixtures this happens when the line V dash M dash coincides with the tie line through the feed point. So, both the V dash M dash coincides with the tie line but for some highly non ideal mixtures it.

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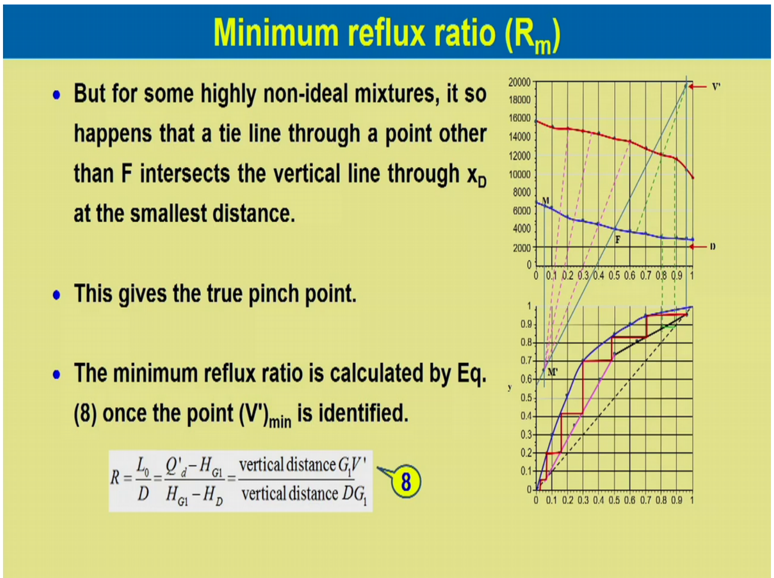

So, happens that a tie line through a point other than F intersects the vertical line through x D at smallest distance. So, this gives the true pinch point, the minimum reflux ratio is calculated by equation 8 once the point V dash minimum is identified. So, R is equal to L naught by D is equal to Q d dash minus H G 1 by H G 1 minus H D. So, this is the vertical distance G 1 V dash divided by the vertical distance D G 1.

So, once V dash minimum is identified we can calculate the minimum reflux ratio using this equation 8.

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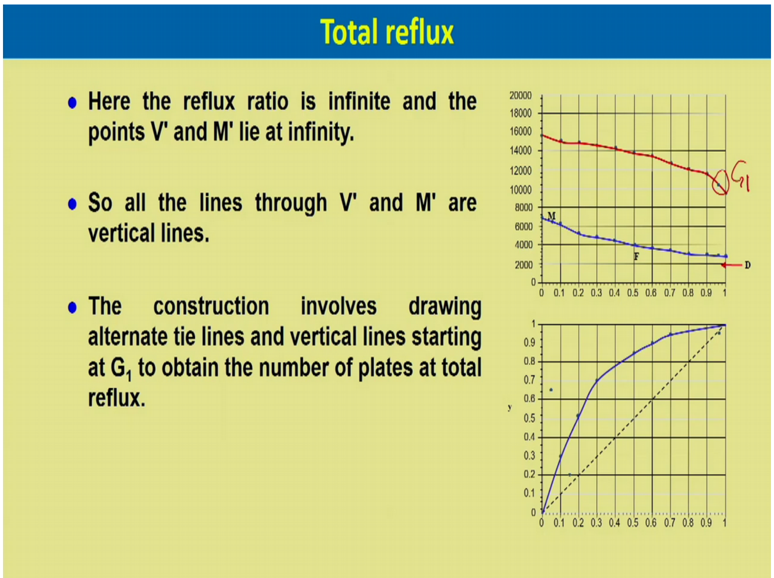

Total reflux ratio is infinite and the points V dash and M dash lie at infinity. So, all the lines through V dash and M dash are vertical lines. The construction involves drawing alternate tie lines and vertical lines starting at G 1 which is over here to obtain the number of plates at total reflux.

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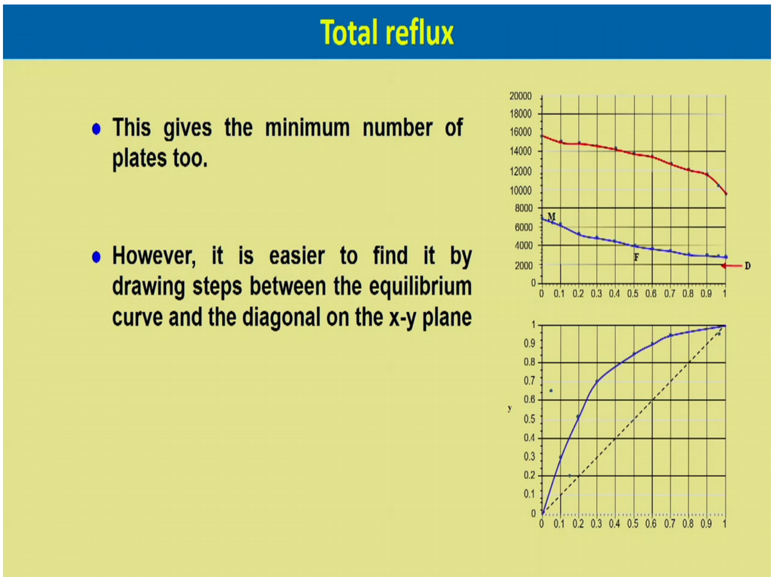

This gives the minimum number of plates too because at total reflux we get minimum number of plates.

However, it is easier to find it by drawing steps between the equilibrium curve and the diagonal on the x y plane. So, as we have discussed earlier if we can draw the x y curve from the H x y curve then it will be much easier to draw the staircase arrangement and to get the number of trays required.

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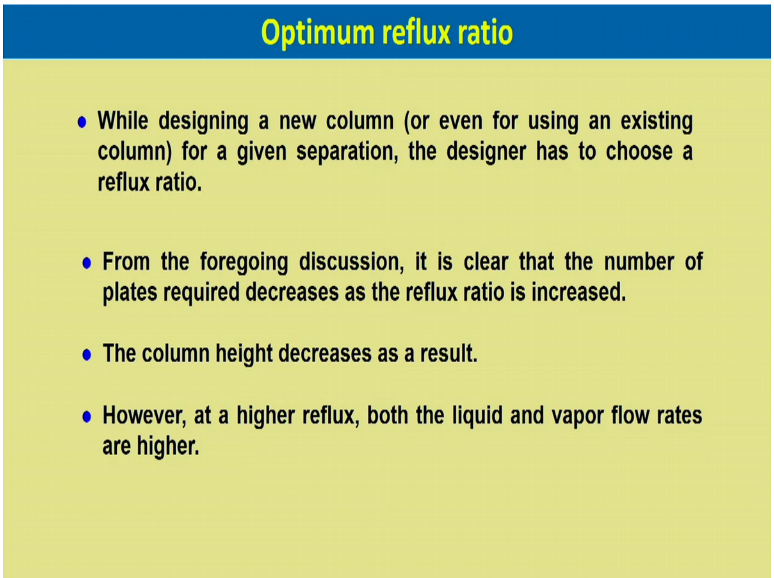

Optimum reflux ratio while designing a new column or even for using an existing column for a given separation the designer has to choose a reflux ratio. From the foregoing discussion it is clear that the number of plates required decreases as the reflux ratio is increased. So, if we increase the reflux ratio the number of plates required will decrease. And at total reflux we have minimum number of trays the column height decreases as a result; however, at higher reflux both the liquid and vapour flow rates are higher.

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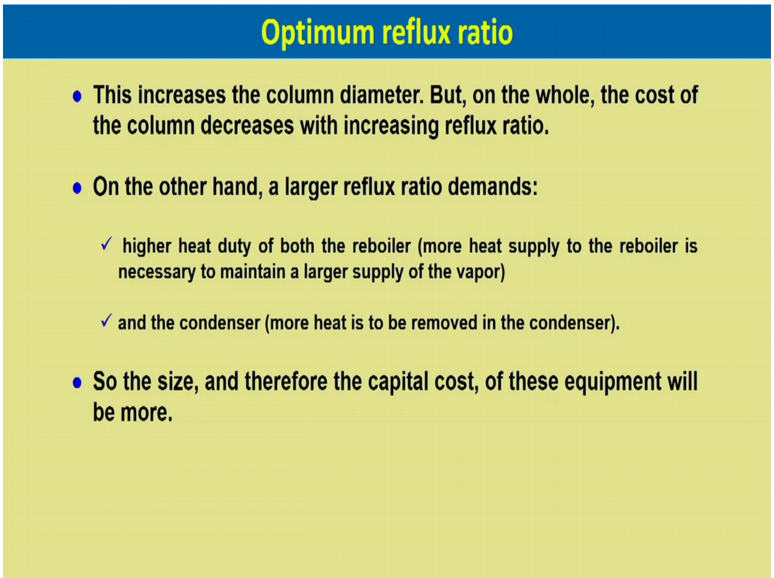

This increases the column diameter, but on the whole the cost of the column decreases with increasing reflux ratio.

On the other hand, a larger reflux ratio demands higher heat duty of both the reboiler more heat supply to the reboiler is necessary to maintain a larger supply of the vapour. And the condenser more heat is to be removed in the condenser. So, the size and therefore, the capital cost of these equipments will be more.

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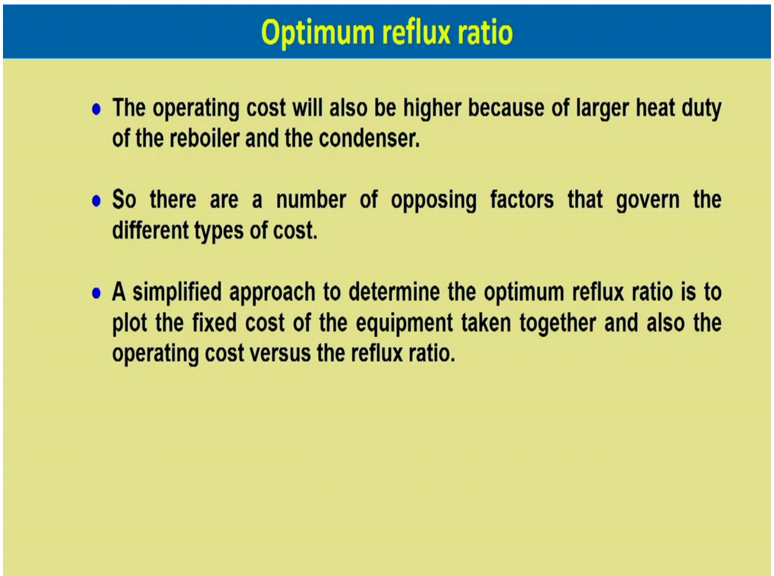

The operating cost will also be higher because of large heat duty of the reboiler and the condenser. So, there are a number of opposing factors that governs the different type of cost.

A simplified approach to determine the optimum reflux ratio is to plot the fixed cost of the equipment taken together and also the operating cost versus the reflux ratio.

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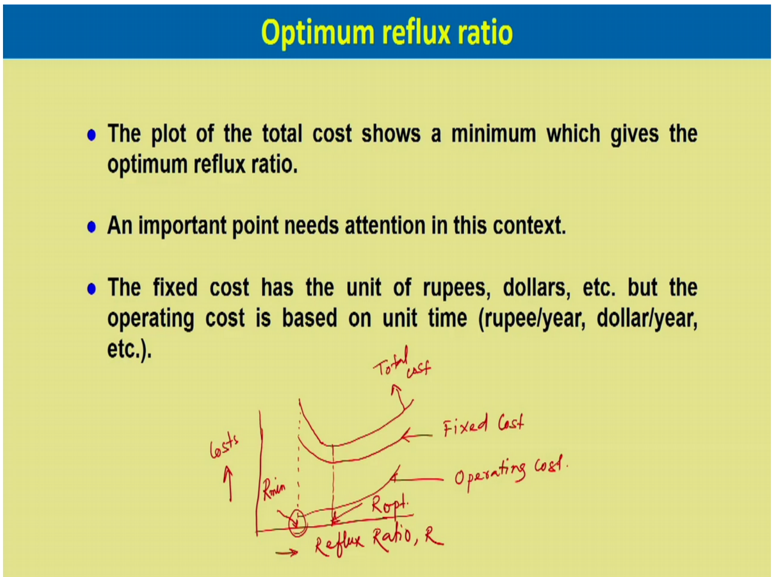

So, the plot of the total cost shows a minimum which gives the optimum reflux ratio. Now if we plot y axis is costs x axis is reflux ratio. So, this is the total cost curve and this is the fixed cost and this one is for the operating cost. So, fixed cost and operating cost and this is the total cost.

So, the plot of the total cost shows a minimum which gives the optimum reflux ratio. So, at the minimum if you plot. So, this is the optimum R optimum. So, this is optimum reflux ratio and this is the reflux ratio which is minimum. An important point needs attention in this context. The fixed cost has the unit of rupees, dollar etcetera, but the operating cost is based on the unit time that is rupees per year or dollar per year and so on.

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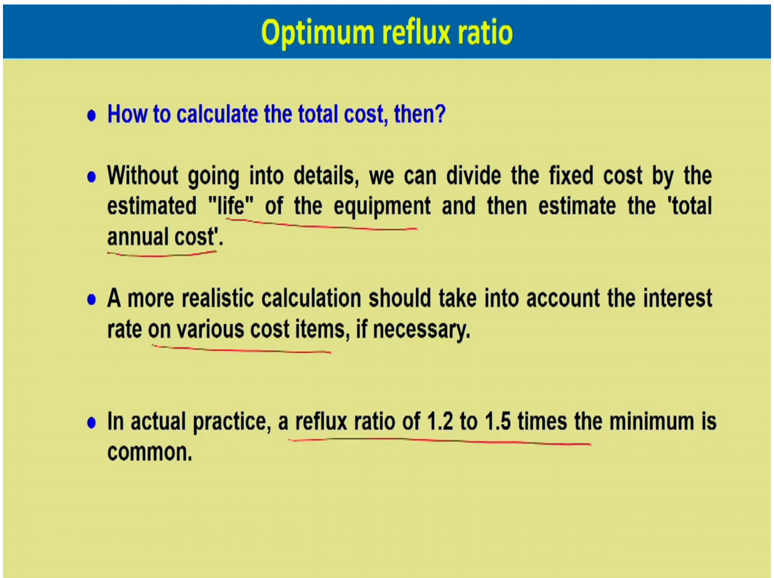

So, how to calculate the total cost then? Without going into details we can divide the fixed cost by the estimated life of the equipment and then estimate the total annual cost. A more realistic calculation should take into account the interest rate on various cost items if necessary.

In actual practice a reflux ratio of 1.2 to 1.5 times the minimum is a common practice to use.

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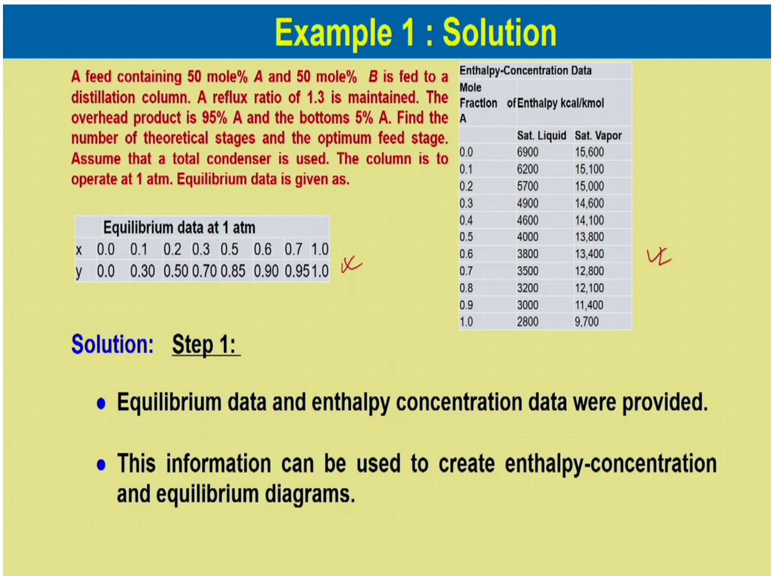

Now, let us take an example to calculate the number of stages required and the optimum feed stage. A feed containing 50 mole percent is A and 50 mole percent B is fed to a distillation column A reflux ratio of 1.3 is maintained. The overhead product is 95 percent A and the bottoms 5 percent A. Find the number of theoretical stages and the optimum feed stage assume that a total condenser is used the column is to be operated at one atmosphere. The equilibrium data is given and the enthalpy concentration for the system is also given.

So, this is the equilibrium data x y data. And this is the H x y data. Now step one we need to draw the equilibrium curve and the enthalpy concentration curve based on the data feature provided this information can be used to create enthalpy concentration and equilibrium.

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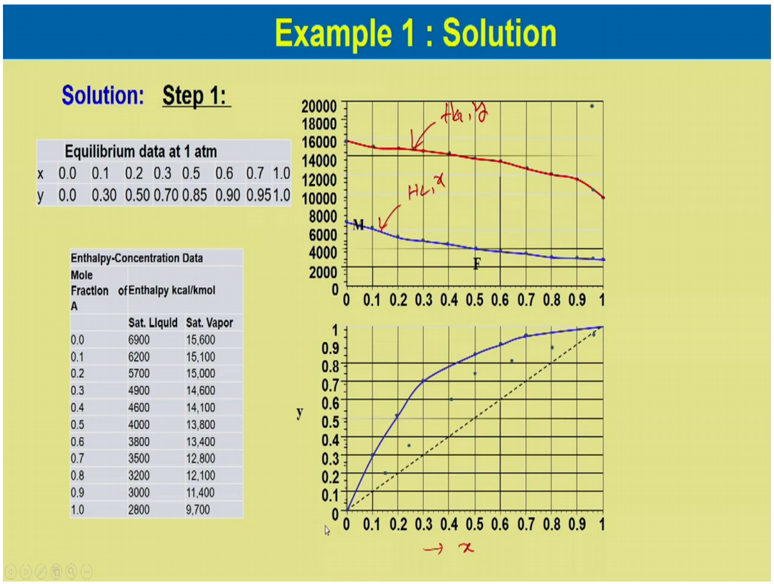

Diagrams as you can see it is plotted over here. So, you have enthalpy concentration diagram. So, this is H G y and this is H L x this is x. So, this is x y diagram.

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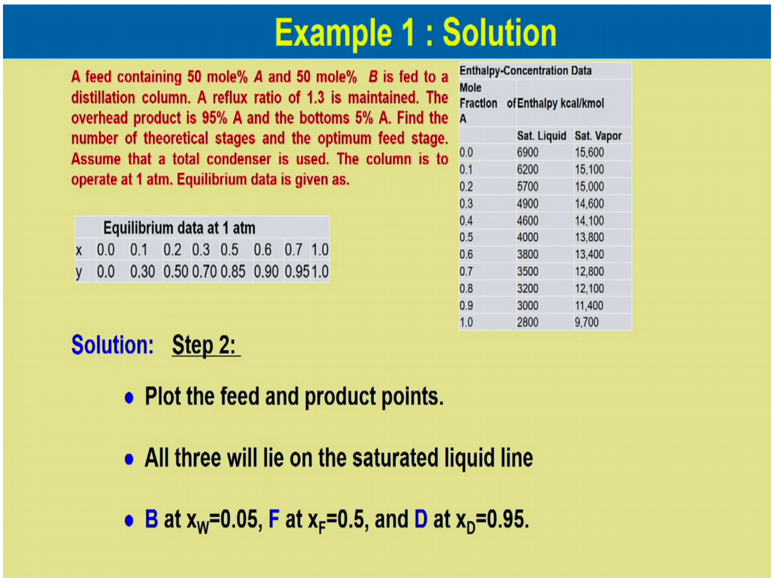

Step 2 plot the feed and product point. We have to locate those feed and product points. All 3 will lie on the saturated liquid line. B at x W would be equal to 0.05 F at x F equal to 0.5 and D at x D is equal to 0.95; so, x W x F and x D. So, these are known. So, that has to be located on the diagram.

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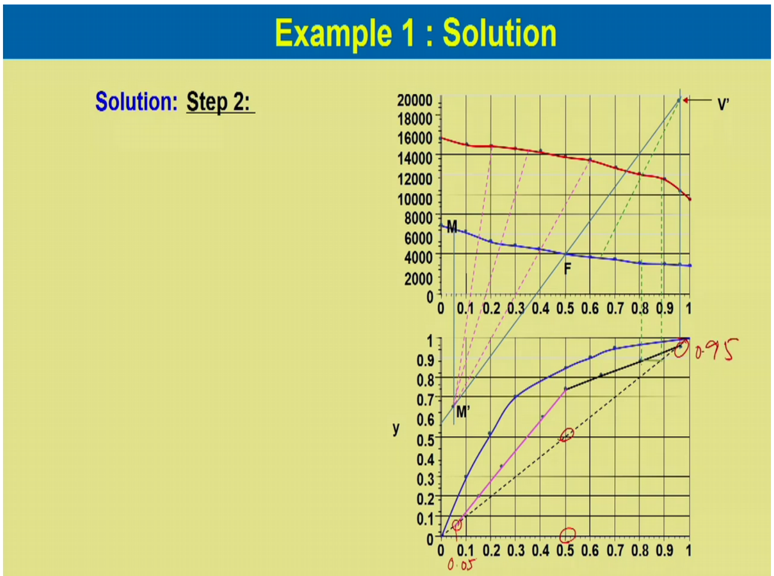

So, we can locate the point. This is 0.05 this is feed point 0.5 and this is 0.95.

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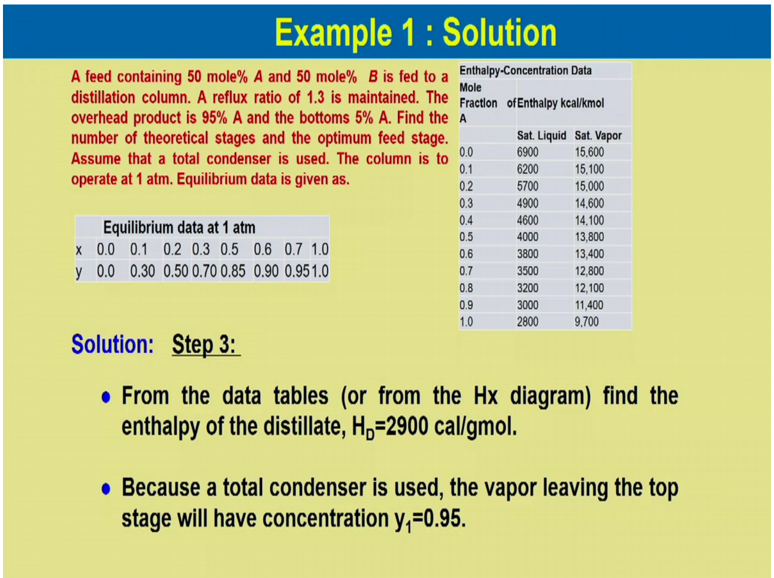

Step 3 from the data tables or from the H x diagram find the enthalpy of the distillate that is HD is equal to 2900 calorie per gram which is given. Because a total condenser is used the vapour leaving the top stage will have the concentration y1 is equal to 0.95. So, we can calculate the enthalpy H G 1 which is 10200 from here from this table. These values and the reflux ratio can be used to find the enthalpy coordinate for the D dash point that is HD p.

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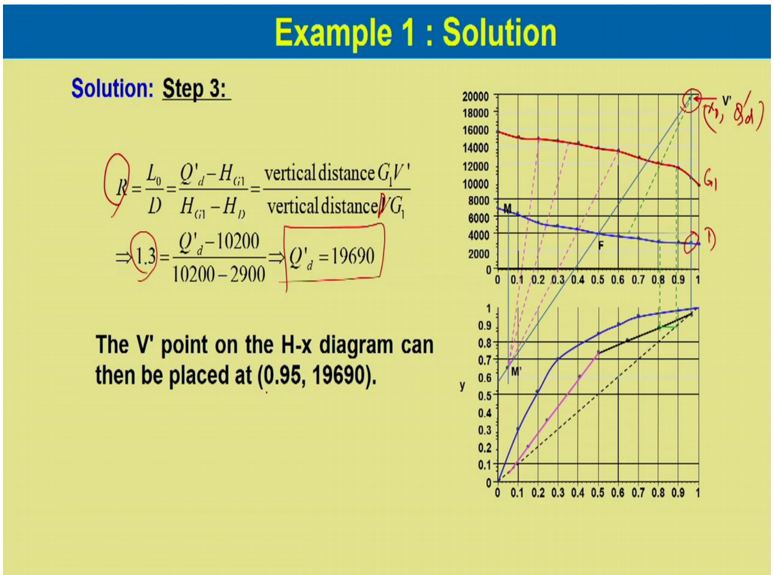

So, reflux ratio we can calculate this is D G 1 R is equal to L naught by D which is equal to Q d dash minus H G 1 divided by H G 1 minus HD which is equal to vertical distance G 1 V dash this is G 1. And this is V dash divided by the vertical distance that is D G 1. So, D is over here. If we put the values, then we will have Q d the reflux ratio is given which is 1.3. Q d dash minus 10200 H G 1 divided by 10200 minus 2900 from here we can calculate Q d is equal to 19690.

So, which is located over here this point is x D Q d x D Q d dash. The V dash point on the H x diagram can be placed at 0.95 and 19690 as we have discussed.

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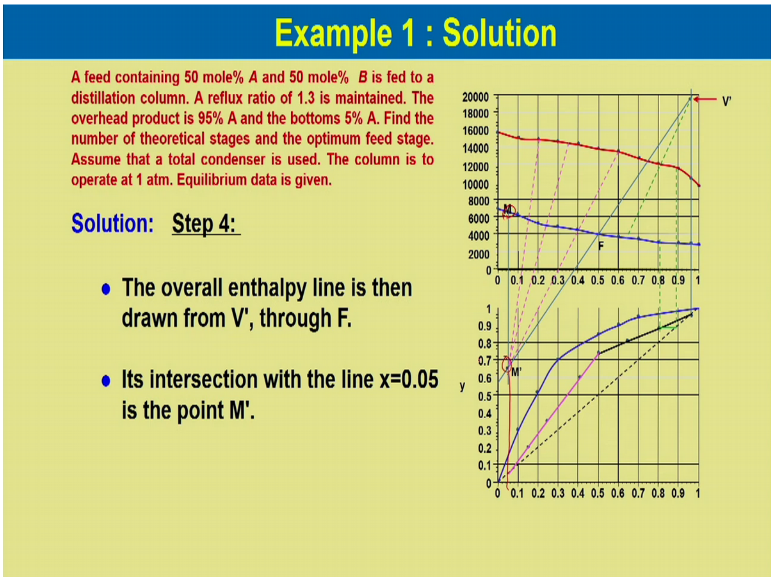

Step 4 the overall enthalpy line is then drawn from V dash through F. It is intersects with the line x is equal to 0.05 which is from here. It is at 0.05. So, from here if you draw vertical line, so, it will intersect at this location.

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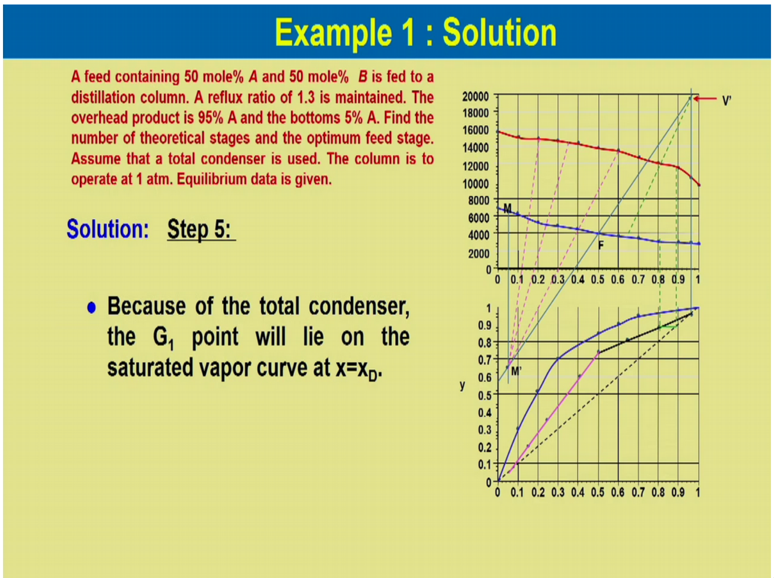

Because of the total condenser the G 1 point will lie on the saturated vapour curve that is x is equal to x D.

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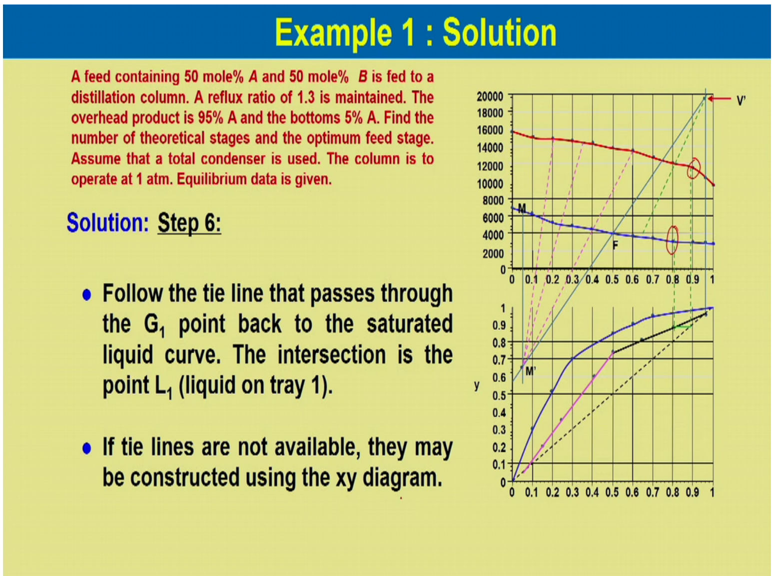

So, which is over here follow the tie line that passes through the G 1 point back to the saturated liquid curve. The intersection is the point L 1 which is liquid on tray one.

So, we can get the tray 1 over here. If tie lines are not available, they may be constructed using the x y diagram.

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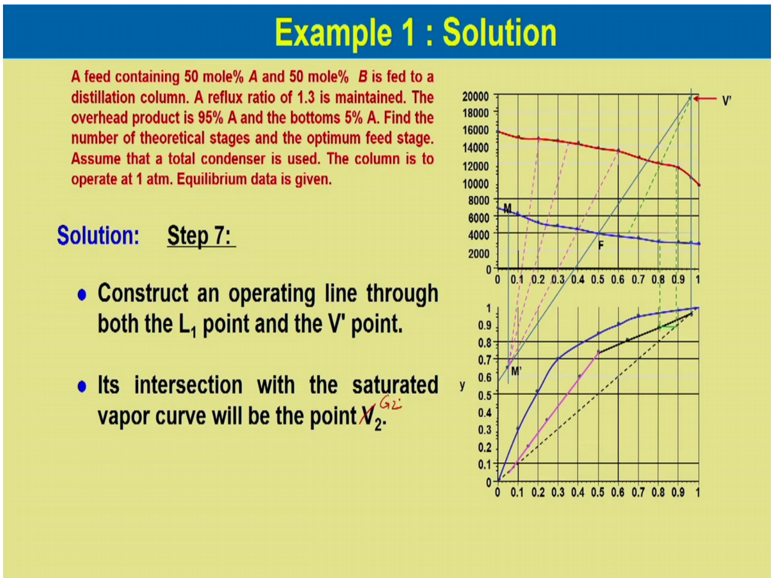

Now, step 7 construct an operating line through both L 1 point and V dash point which is drawn over here in the bottom curve. It is intersection with the saturated vapour curve will be the point V 2 or it is we can say it as G 2.

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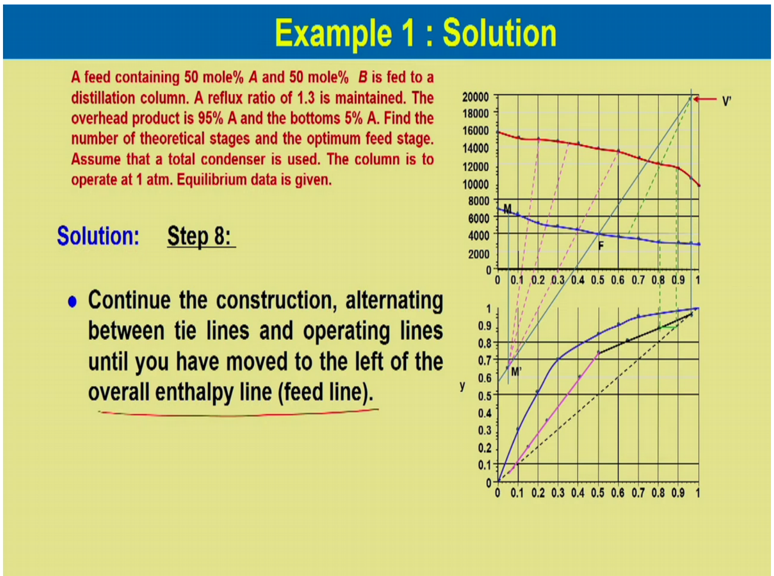

Continue the construction alternating between the tie lines and the operating lines until you have moved to the left to the overall enthalpy line that is feed line.

So, this construction will proceed till you we move to the or cross to the feed line.

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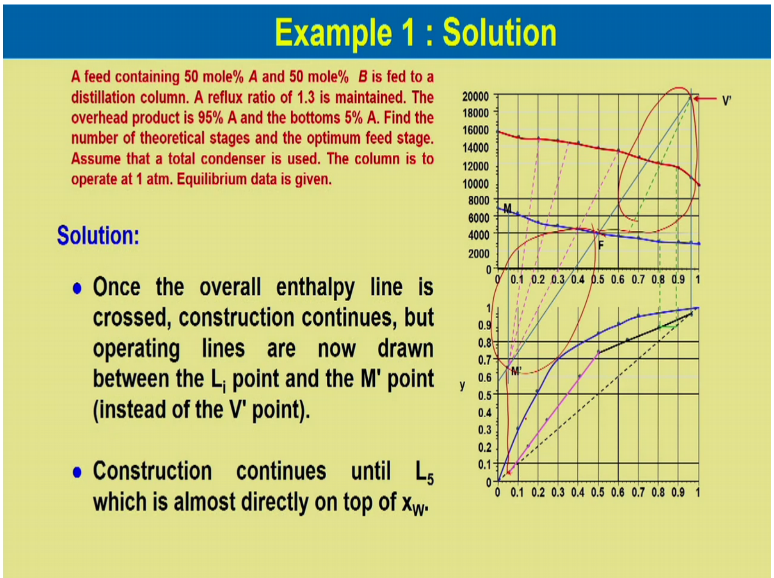

Once the overall enthalpy line is crossed construction continues, but operating lines are now drawn between the Li point and the M dash point instead of V dash point. So, that is for stripping section. So, that is for the bottom section and we have drawn for the stripping section this side. Construction continues until L 5 which is almost directly on top of the x W which is over here from the bottom curve also you can see there are 5 number of plates which are required.

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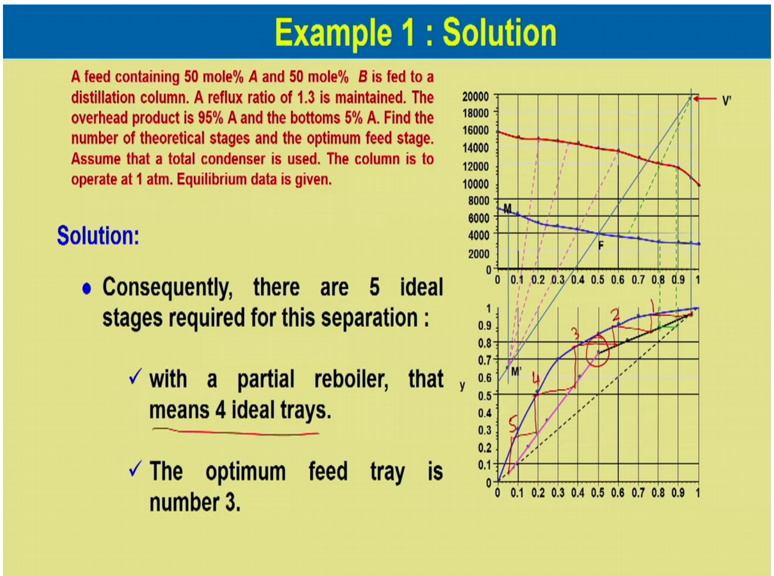

Consequently, there are 5 ideal stages required for this separation with a partial reboiler; that means, 4 ideal trays. So, this total number of trays include the partial reboiler that is also considered as an equilibrium stage. So, 4 ideal trays are required. The optimum feed tray location is tray 3 third tray from this point if we just draw. So, total 5 tray and you can see the cross over is over here. So, feed tray is in the tray 3 and the optimum feed tray location is tray number 3.

Thank you for attending this lecture. And we will continue our discussion on distillation operation in the next lecture.