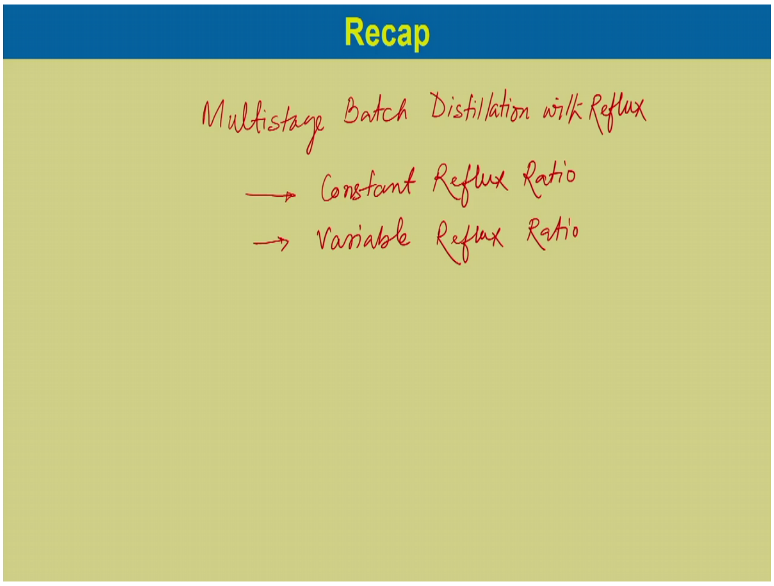
Mass Transfer Operations-I
Prof. Bishnupada Mandal
Department of Chemical Engineering
Indian Institute of Technology, Guwahati

Distillation
Lecture – 36
The Ponchon-Savarit method - I

Welcome to 11th lecture of module 5. In this module we are discussing distillation operation. Before going to this lecture, let us have brief recap on our previous lecture.

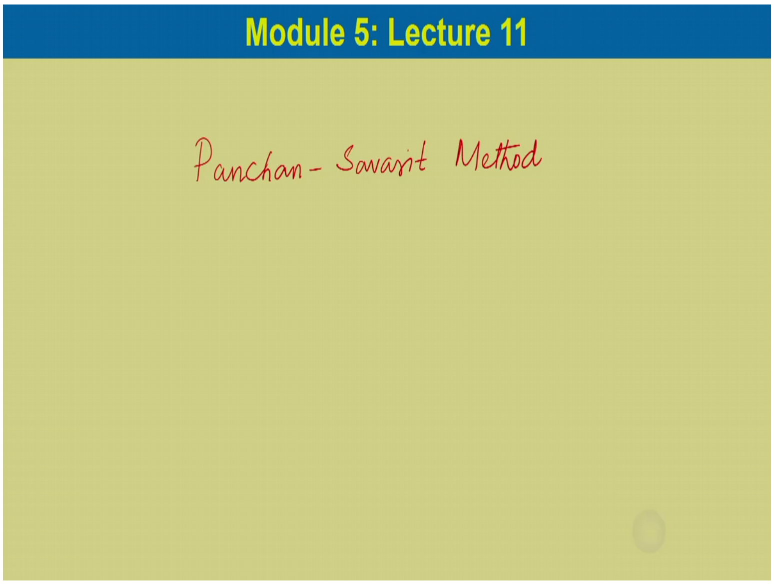
(Refer Slide Time: 00:53)



Last lecture we mainly discussed one important thing which is multistage batch distillation with reflux. Multistage batch distillation with reflux can be run in 2 different conditions. One is constant reflux ratio and second one is variable reflux ratio.

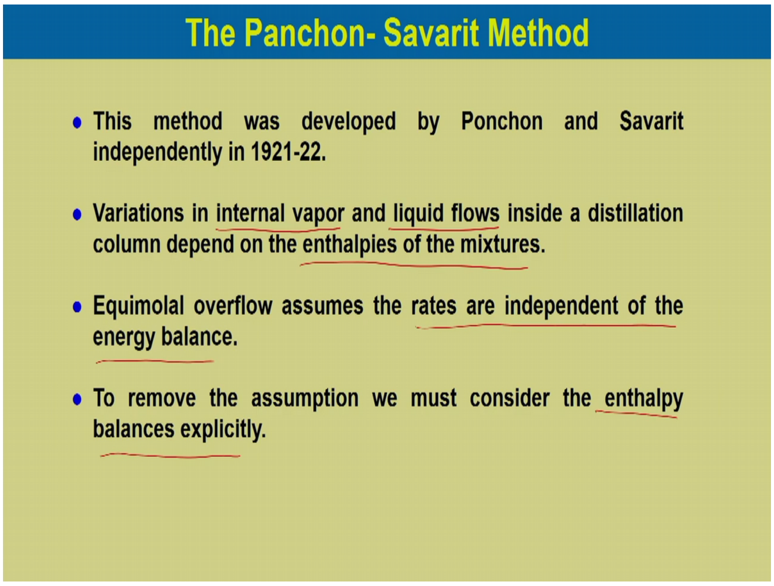
So, both the conditions we have discussed and we have solved 2 different examples for both the one in each case for the solutions of the multistage batch distillation with reflux. In this lecture we will consider very important design aspect of tray column by Ponchon and Savarit method.

(Refer Slide Time: 01:57)



So, let us start with this important topic for design of tray towers in a rigorous manner Ponchon and Svarit method.

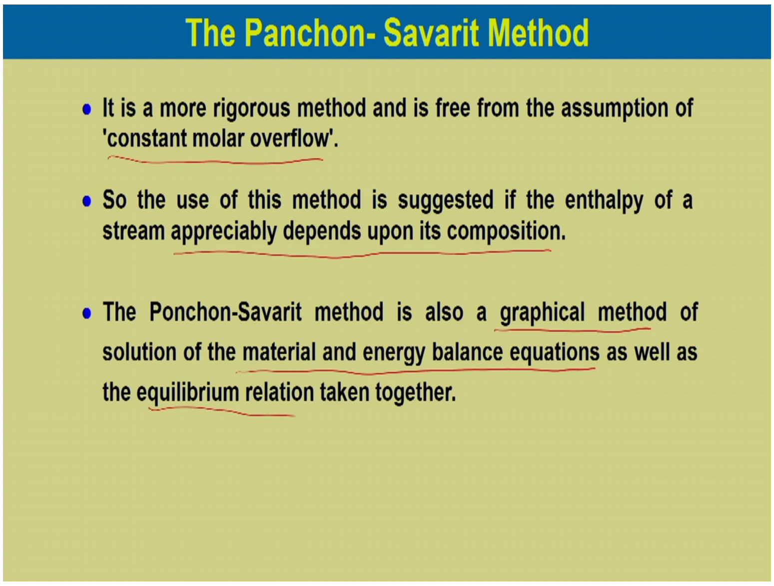
(Refer Slide Time: 02:17)



This method was developed by Ponchon and Savarit independently in 1921-22. In this case the variations in internal vapour and liquid flows inside a distillation column depend on enthalpies of the mixture. So, equimolal overflow which we have assumed for the McCabe Thiele method of design of distillation column their rates are independent of the energy balance. So, we need not to have this change of flows inside the column because we have considered only equimolal overflow for all the trays inside the column.

So, we need not to have the energy balance for that, but to remove these assumption we must consider the enthalpy balance explicitly. So, along with the you know component mass balance and the species mole balance, we need to consider the enthalpy balance equations explicitly with these.

(Refer Slide Time: 03:31)

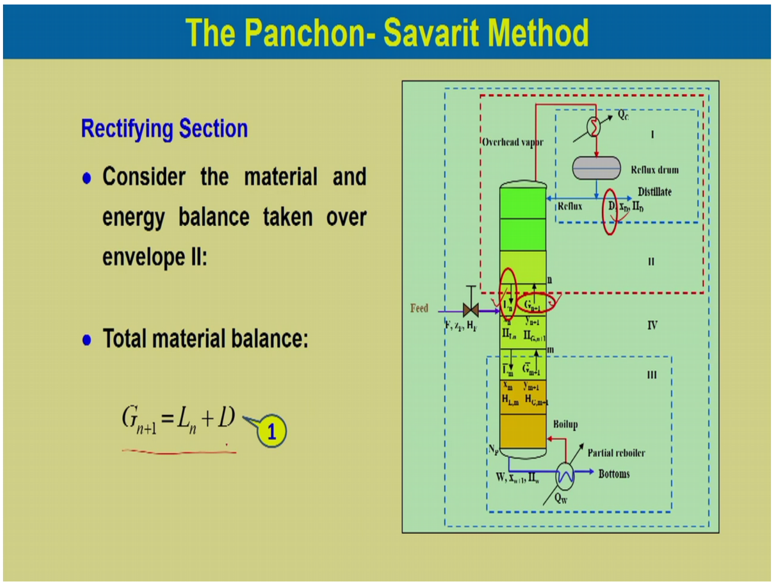


It is a more rigorous method and is free from the assumption of constant molar overflow. We need not to consider this constant molar overflow if we consider the enthalpy balance or energy balance equation it is more rigorous than the McCabe Thiele method.

So, the use of this method is suggested if the enthalpy of a stream appreciably depend upon its composition. So, this method can be used when you have the stream which appreciably depends upon its composition. The enthalpy of the stream will depend upon its composition. So, in that case we can use the rigorous method. The Ponchon Savarit method is also a graphical method of solution of the material and energy balance equation as well as the equilibrium relation taken together. So, this is similar to the McCabe Thiele graphical method of solution. It is also the graphical Ponchon and Savarit method it also the graphical method. In case of McCabe Thiele method, we consider the material balance and the equilibrium relation together to construct the diagram and find out the graphically find out the number of ideal stages required for a particular separation.

This method is also a graphical method that is Ponchon and Savarit method and it requires the material and energy balance equation along with the equilibrium relation. So, altogether can be taken and then the graphically we can calculate the number of stages required.

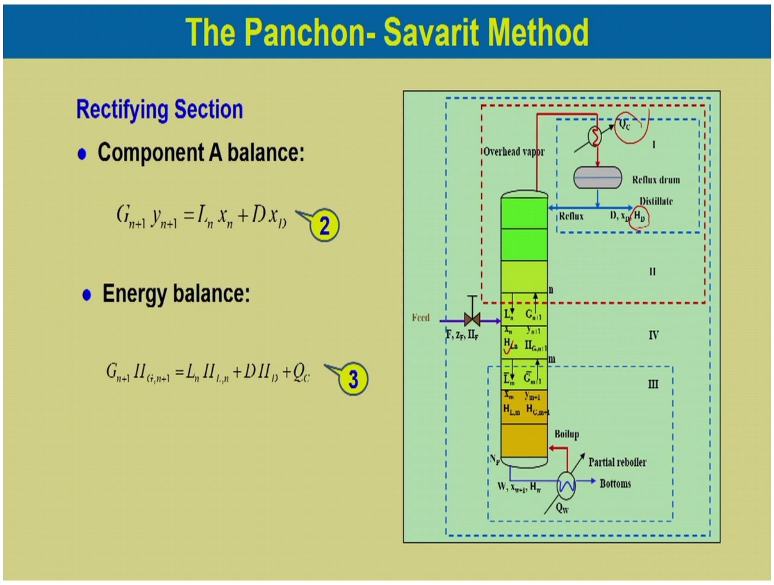
(Refer Slide Time: 05:23)



Let us consider know this multistage tray columns or fractionator as we have discussed before. And we have different sections over here. Section one which you know constitute taking the condenser then reflux drum together and then the envelope to consider the rectifying section you can see over here. It is above the feed ray and it takes all part of the rectifying section. And section 3 it consider the know stripping section and this section 4 which constitute the overall fractionator.

Now, let us consider the material and energy balance taken over envelope 2. So, that is the rectifying section. So, the total material balance in this section we can write you can see G n plus 1 which is over here then the tray entering gas into tray n is G n plus 1. And outgoing stream in this section is the distillate D over here and the liquid which is coming out from tray n, so, which is L n; so, L n and distillate. So, if we do that total material balance in this section, it would be G n plus 1 would be equal to L n plus D. So, this is equation 1.

(Refer Slide Time: 07:13)

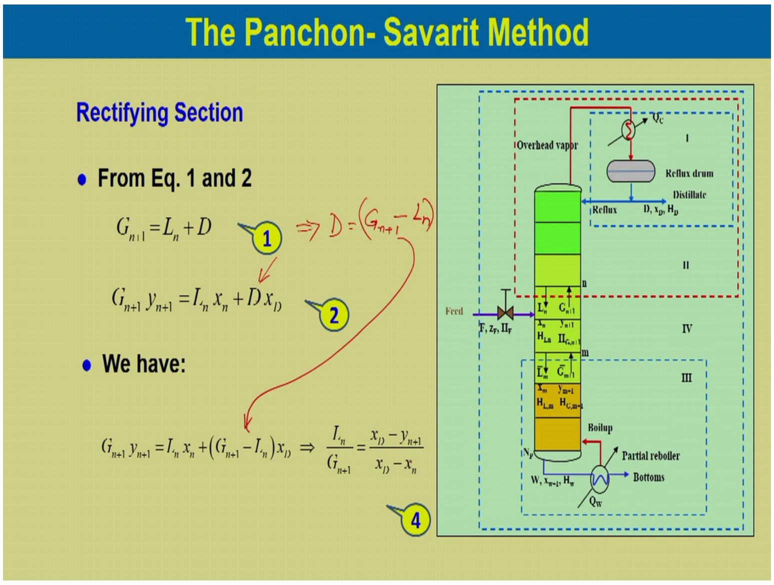


Now, if we do a component mole balance component A balance. So, it would be G n plus 1 into y n plus 1 because its composition is y n plus 1 which is coming to tray n the vapour and the liquid which is living having composition x n. So, it is L n x n and the D that distillate which is you know taken as the over rate product in the rectifying section is D into x D. So, this is the component balance equation 2. Now we have to consider the energy balance equation.

So, if the enthalpy of the vapour which is coming to tray n from tray n plus 1 here tray numbering is done from top 1 2 3 as per the usual convention we use. So, the enthalpy of the vapour which is coming to tray n having know enthalpy of H G n plus 1 and the liquid which is coming down from the tray n having the enthalpy of H L n.

Similarly, the distillate which is taken out having composition of x D mole fractions of the know distillate. And the enthalpy of the distillate is H D. So, we can write the energy balance equation, G n plus 1 into H G n plus 1 would be equal to L n H L n plus D H D plus Q C. So, because of condensation of the know vapour at the top tray, if we just remove heat say Q C for the condensation of the vapour. So, that has to be added which is taken out; so, Q C which is over here.

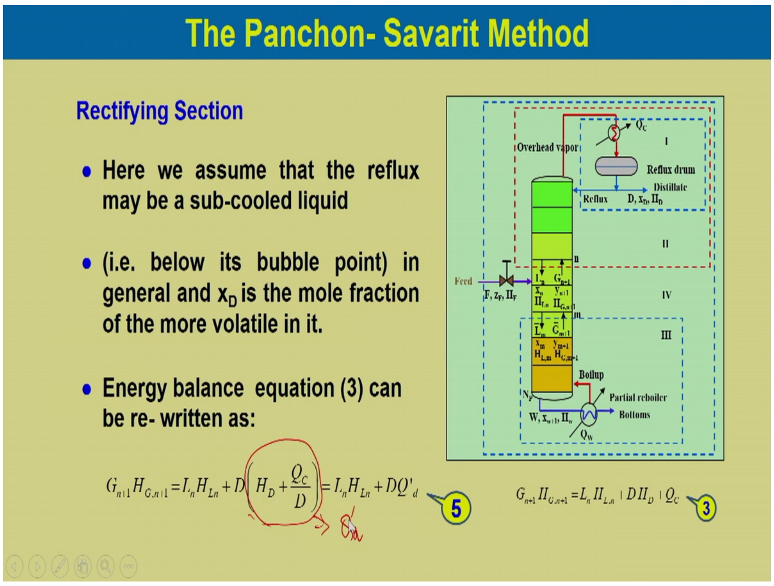
(Refer Slide Time: 09:21)



Now, from equation 1 and 2, so, this is in the overall mass balance and the material balance equation, we can write G n plus 1 into y n plus 1 would be equal to L n x n plus if we substitute know in place of D if we substitute G n plus 1 minus L n. So, from these we can write D would be equal to G n plus 1 minus L n.

So, this is substituted over here in place of D. If we rearrange or simplify it would be L n by G n plus 1 would be equal to x D minus y n plus 1 divided by x D minus x n. So, this is equation 4.

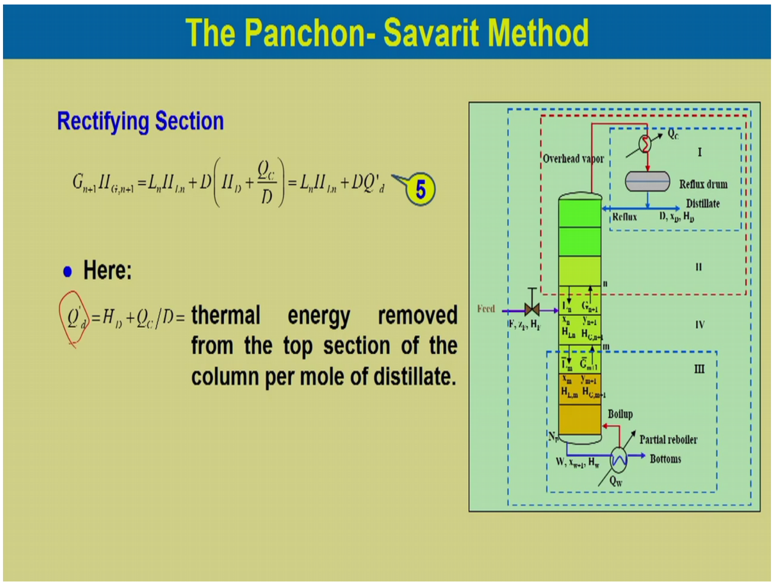
(Refer Slide Time: 10:25)



Now, here we assume that the reflux may be a sub-cooled liquid. So, if it is reflux is a know not saturated liquid, if it is a sub-cooled liquid that is below its bubble point. In general, and x D is the mole fractions of the more volatile in it then the energy balance equation 3 which is over here. In this case we can know write just simplify this G n plus 1 into H G n plus 1 would be equal to L n H L n plus D into H D plus Q C by D.

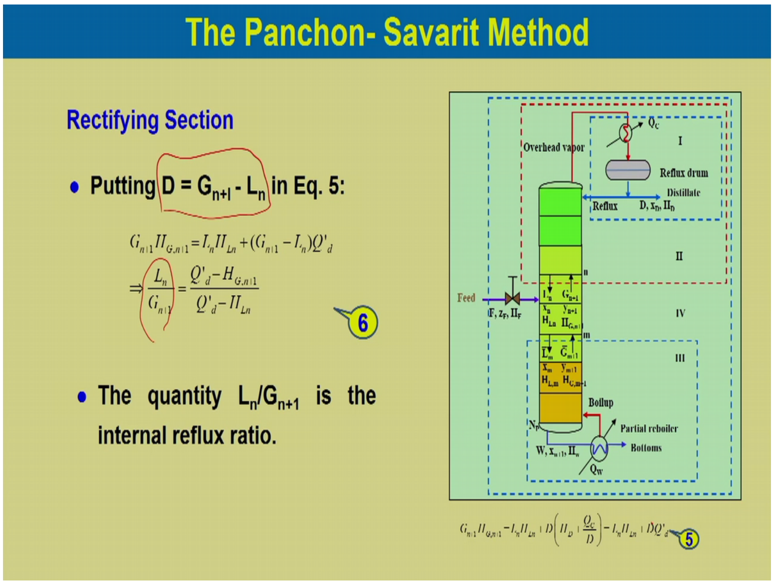
So, in this case it would be L n H L n plus D into Q d dash. So, this is Q d dash.

(Refer Slide Time: 11:45)



So, here Q d dash is H D plus Q C by D. This is thermal energy removed from the top section of that column per mole of distillate. So, that is Q d dash.

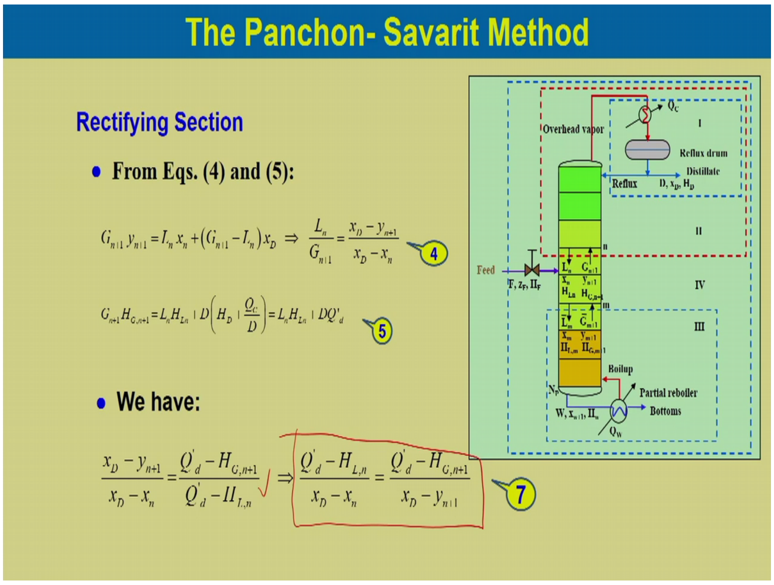
(Refer Slide Time: 12:01)



Now, putting D is equal to from the overall mass balance D is equal to G n plus 1 minus L n in equation 5 this is the equation. So, we can just substitute over here in place of D that is know G n plus 1 minus L n it would be L n by G n plus 1 would be equal to Q d dash minus H G n plus 1 divided by Q d dash minus H L n.

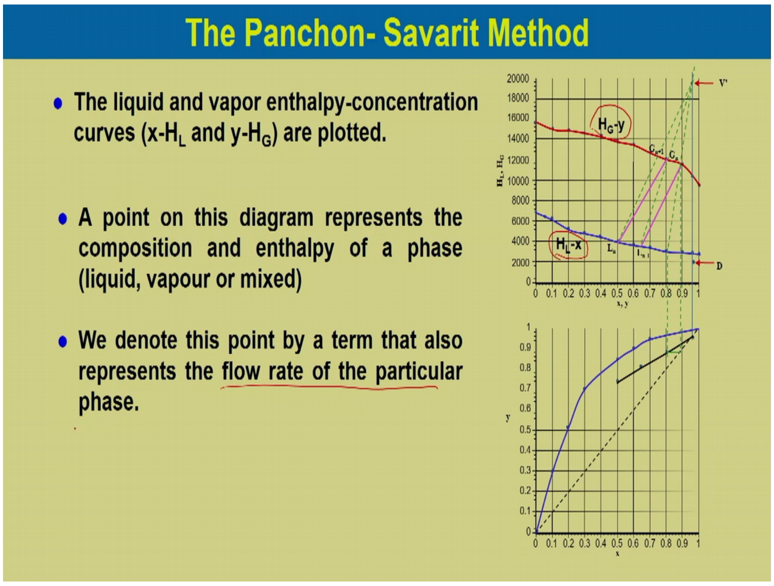
The quantity L n by G n plus 1 is the internal reflux ratio because this is inside the column L by G ratio inside the column. So, it is called internal reflux ratio.

(Refer Slide Time: 12:53)



Now, from equation 4 and 5, from this 2 equation we can write x D minus y n plus 1 divided by x D minus x n would be equal to Q d dash minus H G n plus 1 divided by Q d dash minus H L n. And then we can just rearrange it Q d dash minus H L n divided by x D minus x n would be equal to Q d dash minus H G n plus 1 divided by x D minus y n plus 1. So, this is equation 7. So, we will just know try to understand the significance of equation 7 which we have derived for the rectifying section.

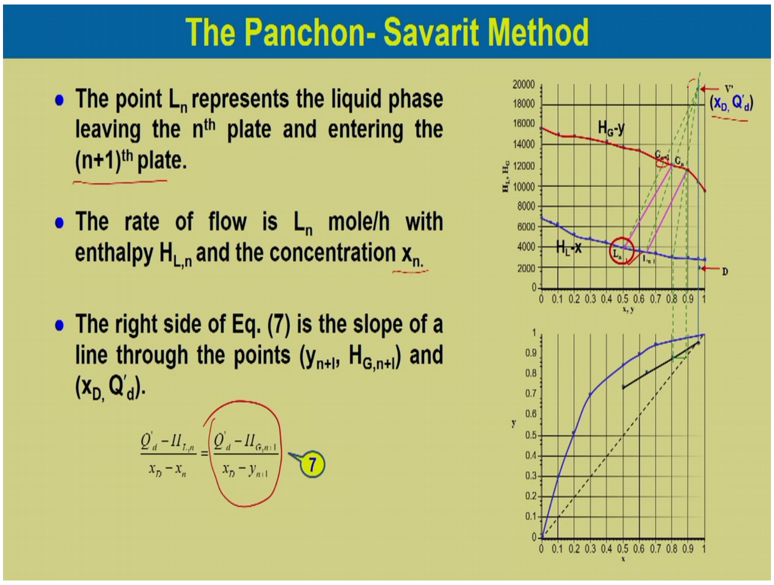
(Refer Slide Time: 13:51)



The liquid and the vapour concentration curves that is H L x or x H L and y H G or H G y that is the enthalpy concentration diagram. That similar to the one which we have discussed earlier can be plotted enthalpy concentration diagram the bottom one over here is blue line is no H L x and the top one is H G y. Enthalpy vapour enthalpy and mole fraction vapour mole fraction and this is H L x liquid enthalpy and mole fraction. So, the liquid and vapour enthalpy concentration diagram. A point on this diagram represents the composition and enthalpy of a phase that is liquid vapour or mixture. We denote this point by a term that also represents the flow rate of the particular phase.

So, that is if it is a liquid. So, it is L liquid flow rate and for that particular tray if it will be L n or L n minus 1 and so on. And similarly to the vapour phase it is gas flow rate to different trays. So, each point on this diagram also represents the flow rate of a particular phase

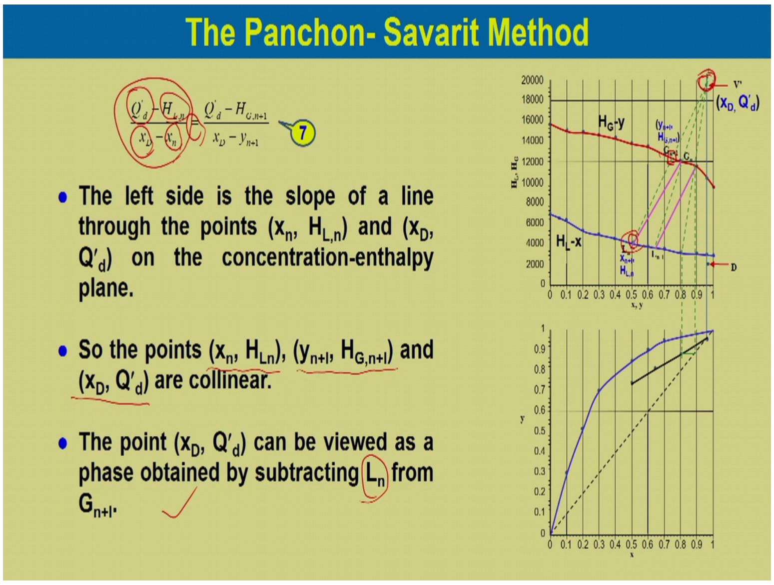
(Refer Slide Time: 15:21)



Now, the point L n represents the liquid phase living the nth plate. So, this is L n shown over here this represents the know liquid phase which is living from tray n and the living stream from tray n if you think about the fractionator it will go to below that tray which would be n plus 1 because the tray number is increasing from top to bottom. The entering plate would be n plus 1 the rate of flow is L n mole per hour with enthalpy H L n and the concentration is x n, the right side of equation 7 which is over here.

The right side of this equation that is Q d dash minus H G n plus 1 divided by x D minus y n plus 1 is the slope of line through the points y n plus 1 H G n plus 1 which is over here, at this location that is G n plus 1 and enthalpy having enthalpy H G n plus 1. And the composition would be of the vapour phase on the enthalpy concentration diagram would be y n plus 1. And it is passing through the point x D and Q d dash. So, which is you know represented over here which is know V dash point V dash.

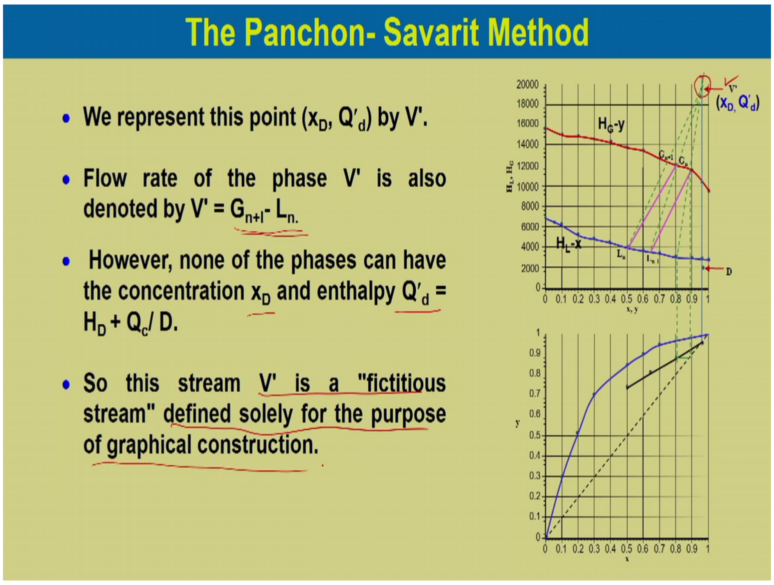
(Refer Slide Time: 17:11)



So, the left side is the slope of a line through the points x n H L n and x D Q d dash. So, if you look into this, this is also the slope of a line through the 2 different points one is x n H L n and another point is x D Q d dash. So, that is on the enthalpy concentration diagram. So, the points this 4 points, this point this point 3 points and this points these are you know x n H L n y n plus 1 H G n plus 1 and Q d and Q dash d are collinear because from equation 7 which is know on developed for the rectifying section considering the overall mass balance species mole balance and the enthalpy balance equation. And this equations left hand side represents a slope passing to 2 different points for the liquid enthalpy concentration diagram, the liquid phase composition at that point and the fictious point that is V dash which is x D Q d dash.

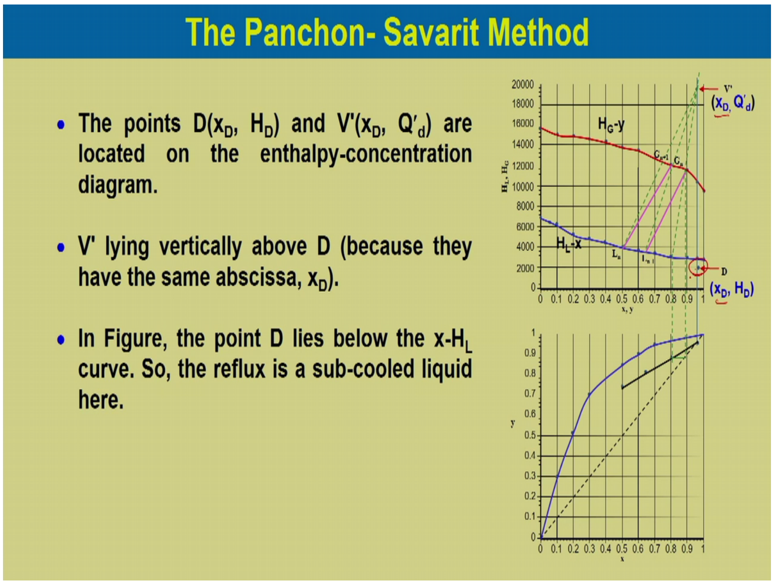
And also the right hand side is another slope of the line having 2 different points. It is a vapour enthalpy and composition point and the 50 such point x D Q d dash. So, this 3 points should be collinear because their slopes are same equal. So, the point Q d x D and Q d dash can be viewed as a phase obtained by subtracting L n from G n plus 1. So, this point this V dash point over here is it can be viewed subtracting L n that is this one from G n plus 1 that can be viewed. So, as we have done during the enthalpy concentration diagram and the conclusion we have made from the geometry of the enthalpy concentration diagram.

(Refer Slide Time: 19:59)



We represent this point that is x D Q d dash by V dash over here. And flow rate of the phase V dash is also denoted by V dash would be equal to G n plus 1 minus L n. Because the V dash can be obtained by subtracting L n from G n plus 1; however, none of the phases can have the concentration x D and enthalpy Q d dash that is Q d plus H D plus Q C by D. So, this stream V dash is a fictitious stream, V dash over here is a fictitious stream defined solely for the purpose of graphical construction.

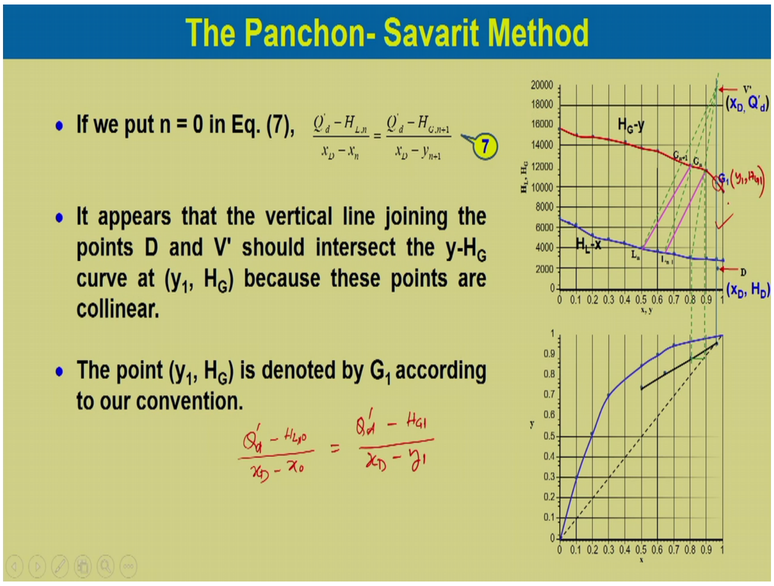
(Refer Slide Time: 21:03)



The point D over here having a know coordinates x D and H D and V dash that is x D and Q d dash are located on the enthalpy concentration diagram. Both are located on the enthalpy concentration diagram V dash lying vertically above D because they have the same abscissa x D. So, for this point D having the same abscissa point that is x D and these V dash is also having x D. So, both of them lying vertically V dash is lying vertically above the D points on the enthalpy concentration diagram.

So, in figure the point D lies below the x H L curve. So, the reflux is a sub-cooled liquid here because while doing the energy balance equations we have considered the reflux which is coming or the condenser cooled the condensate from the from their bubble point. So, it is a sub-cooled liquid. So, it should lie from the saturated liquid composition line. So, which is know that represents the sub-cooled liquid.

(Refer Slide Time: 22:35)

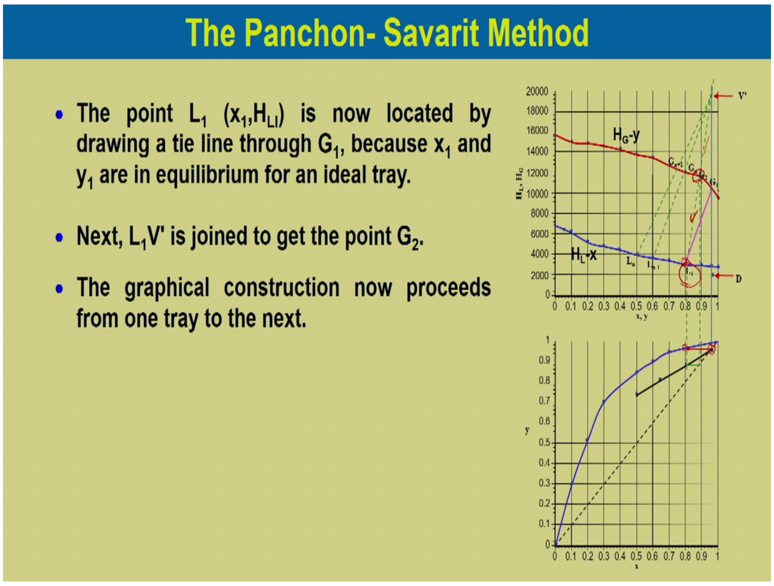


Now, if we put n is equal to 0 because the entering feed or entering reflux from the reflux drum to the tray one we considered L naught.

So, if we put n is equal to 0 in equation 7 in this equation, it appears that the vertical line joining the points D and V dash should intersect with H G y curve at y1 H G because these points are collinear. So, the point y1 and H G is denoted by G1 according to the convention. So, if we put n is equal to 0 what will happen? Over here this equation; equation 7 we can write Q d dash minus H L 0 divided by x D minus x naught would be equal to Q d dash minus H G1 divided by x D minus y1.

So, this know the vertical line joining the point D and V bar. So, this line should intersect the vapour at the point G1, which is shown over here having the point y1 H G. So, its composition would be y1 H G1.

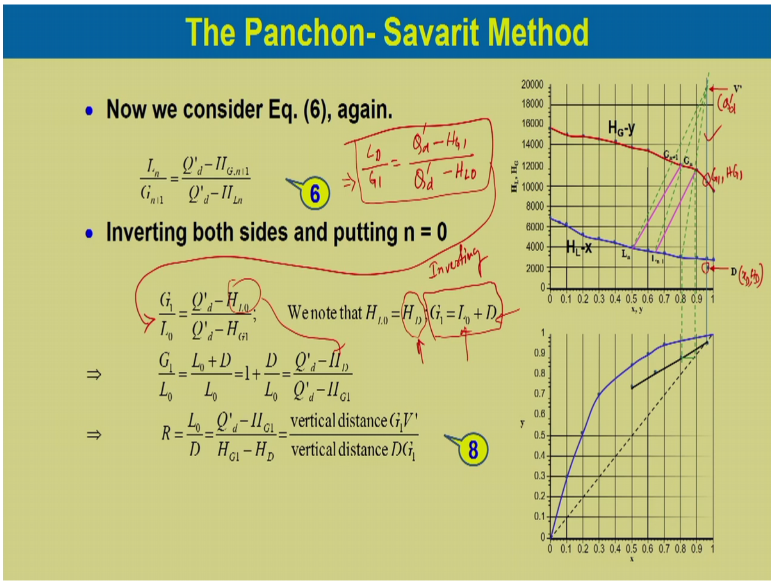
(Refer Slide Time: 24:23)



The point L1 shown over here having the coordinates x 1 H L1 is now located by drawing a tie line through G 1. So, from G1 we can draw a tie line over here and because, x 1 and y1 are in equilibrium for the ideal tray. So, if you have the equilibrium curve over here. So, from this G1 point you can come vertically to the 45 degree diagonal on the bottom x y curve and go horizontally which meets the equilibrium curve over here then if you go vertically to the H L x curve you will find L 1. So, you can join G1 L1 would be your tie line.

So, next L1 V dash is joined to get the point G 2. So, from L1 you can just draw a line from here. And this dotted line shown over here which is crosses to H G y curve and it meets to the V dash. So, this point the intersection point you can find out for the G 2. The graphical construction now proceed from one tray to the next tray according to this convention and find out the number of plates. So, the graphical construction now proceed from one tray to the next and you can get similar know points from tray to tray G1 to G 2 to G 3 and so on up to G n n plus 1. And also you can find from L1 to L 2 to L 3 and so on. So, you can know find out different tie lines.

(Refer Slide Time: 26:25)



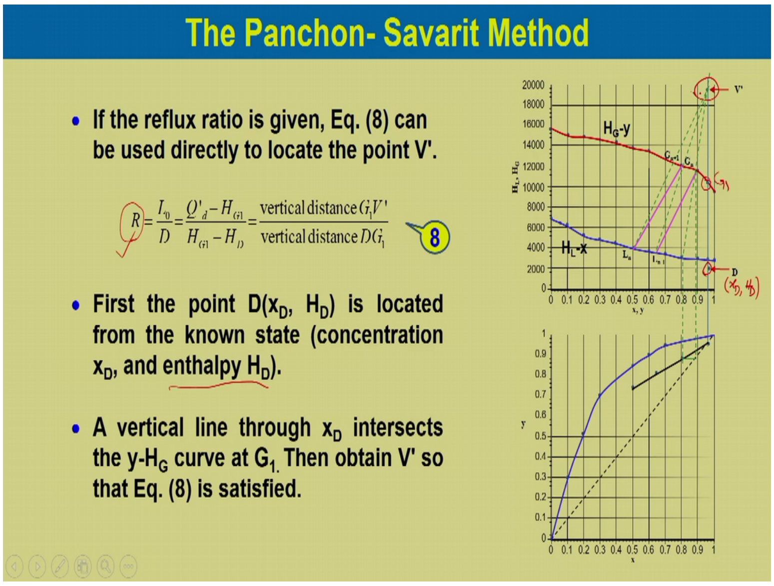
Now, we consider equation 6 again. That is L n by G n plus 1 would be equal to Q d minus H G n plus 1 divided by Q d dash minus H L n. Now inverting both sides and putting n is equal to 0 we obtain if you put over here n is equal to L naught divided by G1 would be equal to Q d dash minus H G1 divided by Q d dash minus H L naught. This equation if you invert then you will obtain by inverting we will get G 1 by L naught would be equal to Q d dash minus H L naught divided by Q d dash minus H G 1. So, we note that H L naught would be H D and G1 would be L naught plus D.

If you do the material balance for envelope one, if you just recall our tray column which we have considered at the beginning. And if you do the overall mass balance for the envelope one the vapour which is going up from tray one is condensed. And distillate is taken out the reflux L naught is return back to the column. So, G1 would be equal to L naught plus D. And H L naught would be the same enthalpy as the distillate taken out H D. So now, if we just substitute the values in this equation you will obtain G 1 by L naught would be equal to L naught plus D by L naught which is equal to 1 plus D by L naught which would be equal to Q d dash minus L naught would be H D divided by Q d dash minus H G 1.

So, if we define the external reflux ratio which is L naught by D would be equal to Q d dash minus H G1 divided by H G 1 minus H D; so, this Q d dash and H G 1. So, Q d dash is over here. Q d dash and H G1 this is G1 having the enthalpy H G1. So, this represents G1 and V dash the vertical distance G1 V dash that is this line divided by H G 1 over here this point and the H D which is having know x D H D. So, this point. So, this is the vertical distance between G1 and D that is D G1 and the upper one is the vertical distance G1 V dash.

So, this is the reflux ratio would be the vertical distance G1 V dash divided by vertical distance D G1.

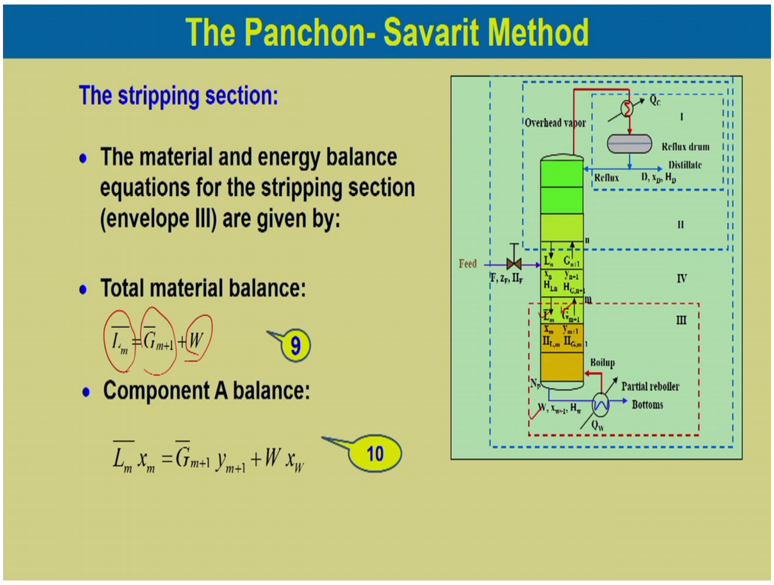
(Refer Slide Time: 30:37)



If the reflux ratio is given, equation 8 can be used directly to locate the point V dash. So, this is the equations we have derived. And reflux ratio is given that is R is given if R is given this is equation 8. The first point D that is x D x D H D this point is located from the known state con concentration x D and enthalpy H D because this is the outlet or the distillate taken out at the top product. So, its a composition and enthalpy is known. So, if this is known a vertical line through x D intersects y H G curve at G 1.

So, this point condition is known and it will intersect over here vertical line it will be G1 then G1 is known. So, then the obtain V dash from equation 8. So, we can calculate V dash from this equation. So, if reflux ratio is known and other parameters are known. So, we can obtain the vertical distance that is V dash.

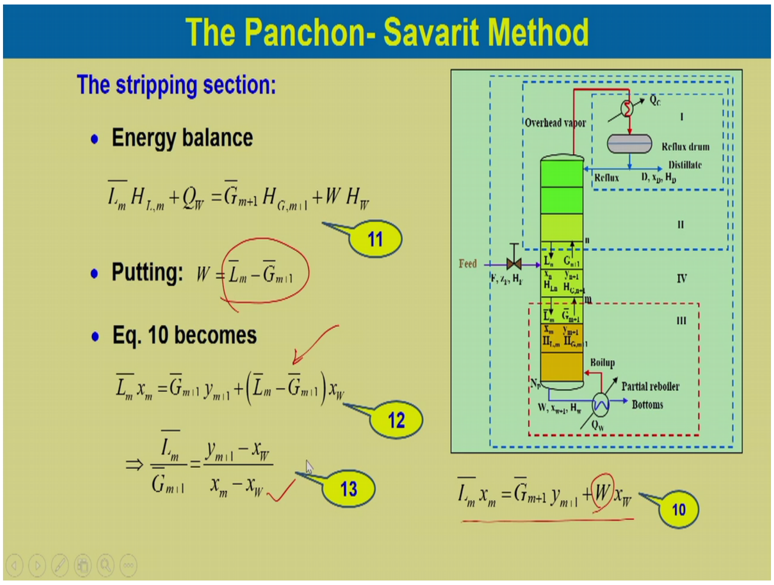
(Refer Slide Time: 32:09)



Now, the stripping section, so, that is below the feed ray the material and energy balance equation for the stripping section that is envelope 3 this is envelope 3 in the stripping section. Which can be written as total material balance that is L m bar would be equal to G m plus 1 bar plus w. Because you can see the entering liquid in this section in the stripping section is L m bar. And then outgoing at the bottom is W and outgoing from G m plus 1th tray is G m plus 1 bar. So, L m bar would be equal to G m plus 1 bar which is shown over here. So, this is total material balance equation 9 is total material balance in the stripping section. Now for the stripping section if we do the component A balance.

So, L m bar having composition of x m is equal to G m plus 1 bar having composition y m plus 1 plus W having composition x W this would be W x w.

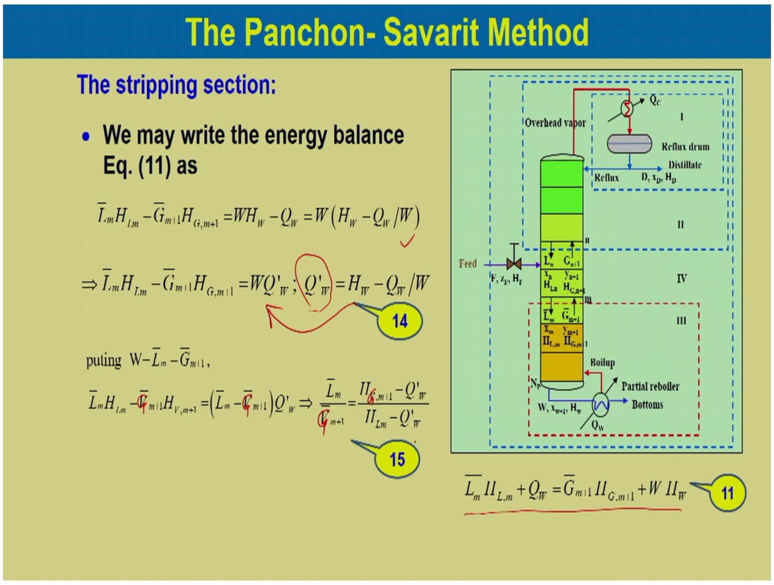
(Refer Slide Time: 33:41)



If we do the energy balance equation, it would be L m bar into H L m plus Q W would be equal to G m plus 1 bar H G m plus 1 plus W into H w. This is equation 11 that is energy balance equation. Now if we just use the total material balance for this section W would be equal to L m bar minus G m plus 1 bar. Then equation 10 over here that is the species mole balance equation L m bar x m would be equal to G m bar into y m plus 1 plus L m bar minus G m plus 1 bar into x w.

So, basically W over here is substituted with L m bar minus G m plus 1 bar here. So, equation 12 can be rearranged to get equation 13 which is L m bar divided by G m plus 1 bar would be equal to y m plus 1 minus x W divided by x m minus x W.

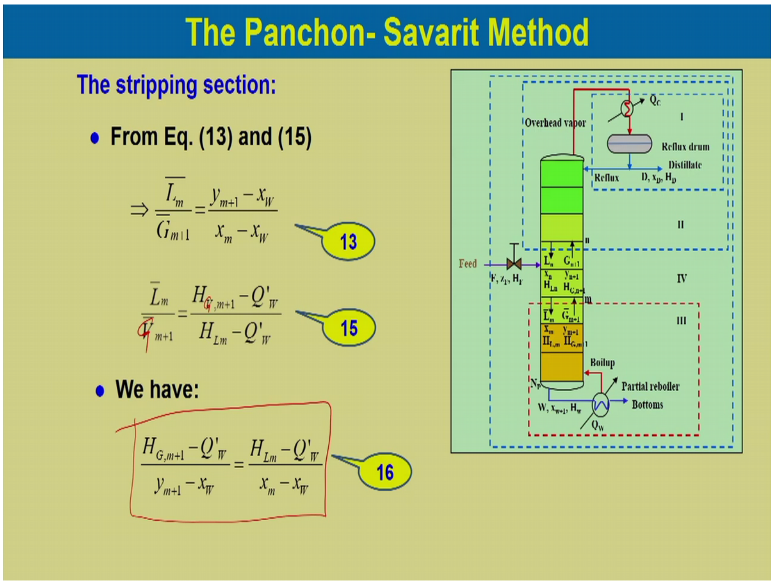
(Refer Slide Time: 34:59)



Now, we may write the energy balance equation 11 which is over here the energy balance equation in the stripping section we can write L m bar H L m minus G m plus 1 bar into H G m plus 1 would be equal to W H W minus Q w.

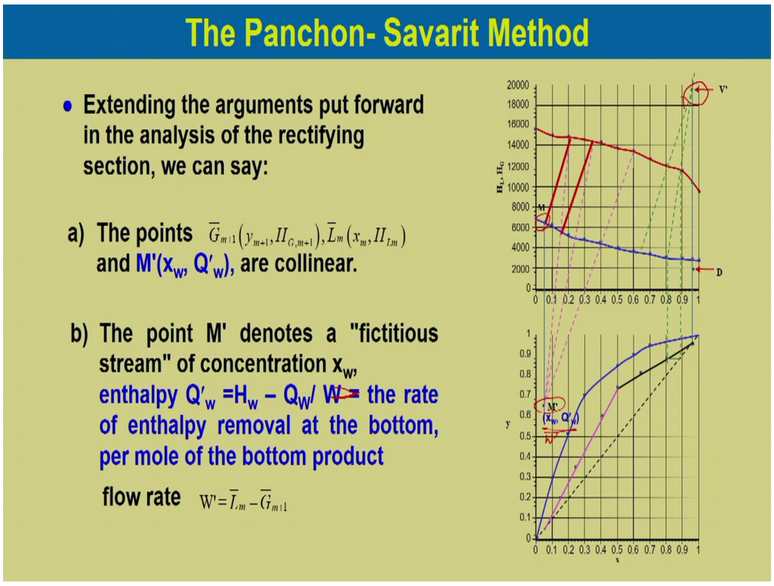
So, by rearrangement we can write W into H W minus Q W by W. And we can write H L m bar H L m minus G m plus 1 bar into H G m plus 1 would be equal to W into Q W dash. So, Q W dash over here is H W minus Q W by W. So, this is equation 14. Now if we use the total material balance equation in this rectifying section in this equation. So, the stripping section equation 14 can be reduced to L m bar divided by V m plus 1 bar, no. this would be G. So, this would be instead of V bar it would be G m plus 1 bar. So, we can write G L m bar by G m plus 1 bar would be equal to H V H G m plus 1 minus Q W dash divided by H L m minus Q W dash. So, this is equation 15.

(Refer Slide Time: 36:57)



Now, from equation 13 and 15, so, we can write know H G m plus 1 minus Q W dash divided by y m plus 1 minus x W would be equal to H L m minus Q W dash divided by x m minus x W. So, we will analyse similar to the rectifying section equation 7. We will discuss this equation in the stripping section and how to calculate the tie line and number of trays in the rectifying section.

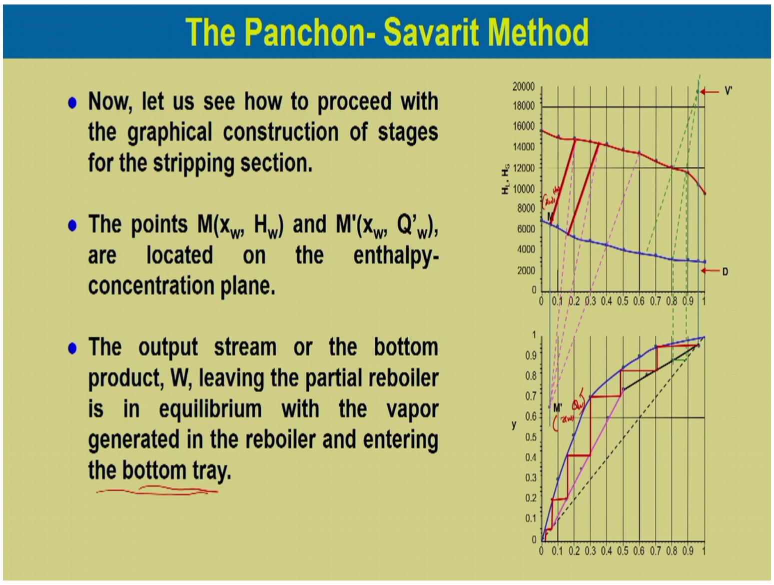
(Refer Slide Time: 37:39)



Extending the arguments put forward in the analysis of the rectifying section. We can say the points G m bar that is having coordinates y m plus 1 H G m plus 1 and L m bar x m H L m and M dash x W Q W dash which is shown over here.

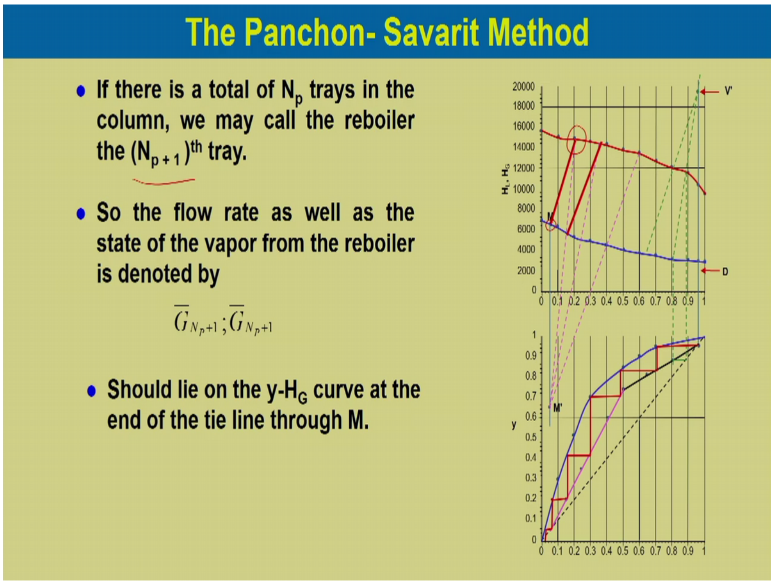
This is M dash this is known M. So, they are collinear, the point M dash also similar to V dash. They are fictitious points streams of concentration the point M dash denotes a fictitious streams of concentration x w. So, which is shown over here and enthalpy Q W dash is equal to H W minus Q W by W. That is the rate of enthalpy removal at the bottom per mole of the bottom product. And the flow rate will have W dash over here which is L m bar minus G m plus 1 bar.

(Refer Slide Time: 39:07)



Now, let us see how to proceed with the graphical construction of stages for the stripping section. The points M which is having coordinates x W and H W and M dash having coordinates x W Q W dash and they are on the enthalpy concentration plane the output stream or the bottom product W leaving the partial reboiler is in equilibrium with the vapour generated in the reboiler and the entering the bottom tray. So, they will be in equilibrium. That is from the boil of which is going from the reboiler to the know bottom tray of the column and the bottoms that is the product which is taken out from the bottom tray.

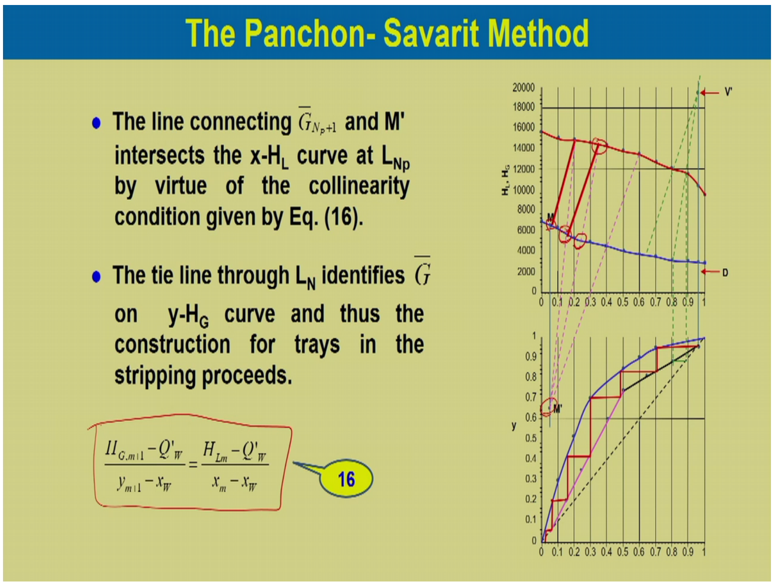
(Refer Slide Time: 40:11)



So, if there is a total N p trays in the column we may call the reboiler as N p plus 1th tray.

So, the flow rate as well as the state of the vapour from the reboiler is denoted by G N p plus 1 and G bar N p plus 1 and G N p plus 1 bar. So, this is the point and it should lie on the y H G curve at the end of the tie line through M. So, which is shown over here.

(Refer Slide Time: 40:55)

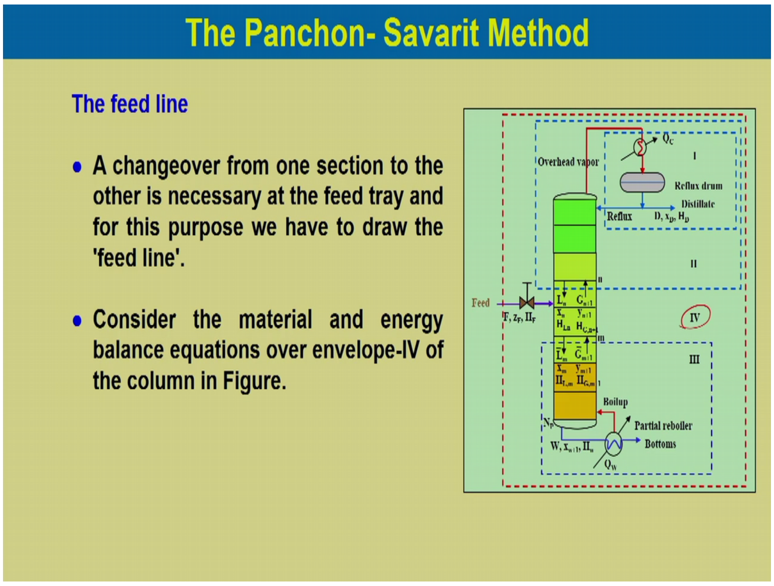


The line connecting G N p plus 1 and M dash intersects x H L curve and L N p by virtue of the collinearity condition given by equation 16. So, this is the collinearity conditions which we have discussed earlier like in case of n reaching section or rectifying section.

Similar collinearity can be obtained from this correlation from equation 16. The tie line through L N identifies G dash on y H G curve and thus the construction for the trays in the stripping section proceed. So, from here like we did from the rectifying section, you can draw the tie line and then join the know tie line you know with the M dash point over here and you will obtain another point on this line. So, again similar to that you obtain the tie line here and join to this point and get the next tray. As you move from the reboiler you will move to the next tray that is from bottom to the upper trays.

So, it will proceed to the G N p plus 1 to G N N p and then G N p minus 1 and so on. So, similar to the procedure we followed for the rectifying section, we can do the similar approach for the stripping section as well.

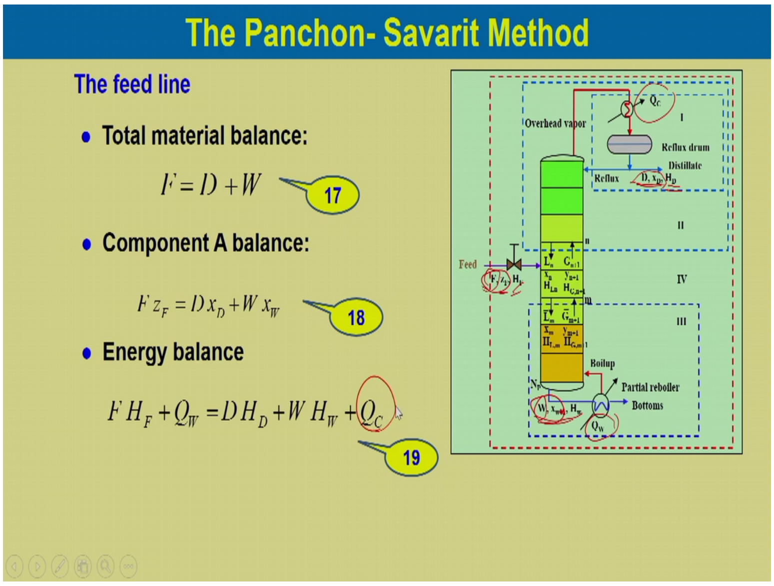
(Refer Slide Time: 42:33)



Now, let us consider the feed line. So, in this case you have know feed conditions which is given. And a changeover from one section to the other is necessary at the feed tray and for this purpose we have to draw the feed line.

So, consider the material and energy balance equation over the envelope 4. So, this is envelope 4 that is the red border envelope the whole envelope which is shown over here in this column.

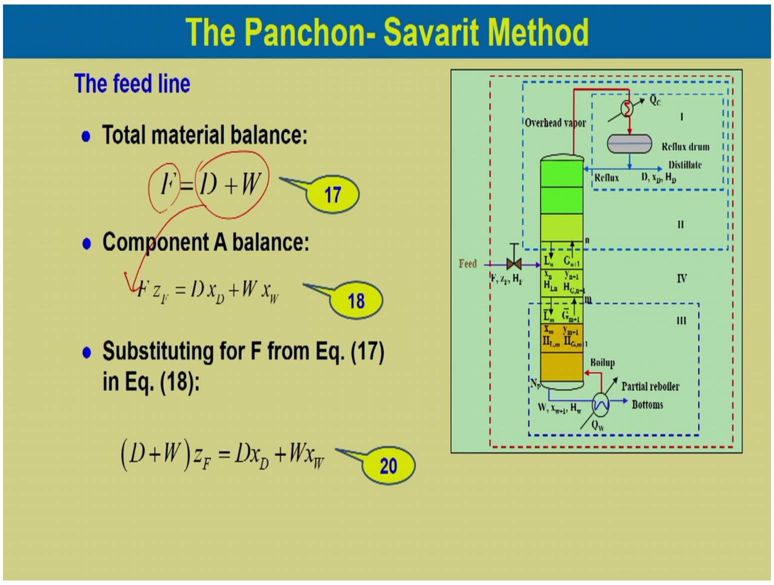
(Refer Slide Time: 43:07)



So, if we do the total material balance, it would be F which is feed is coming over here would be D distillate which is taken out at the top and bottoms which is W over here having composition x W. So, the component balance if we do for this it would be F z F would be equal to D x D and then plus W x w.

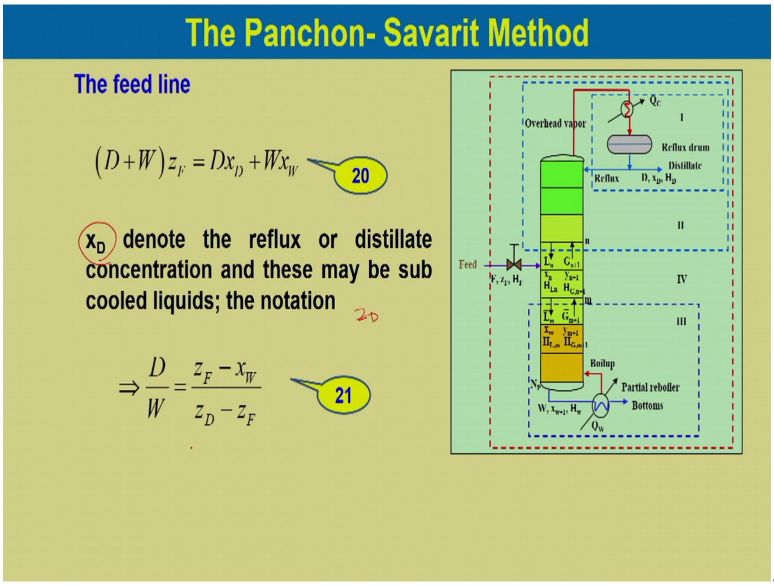
So, this is the component balance and energy balance we can write know F H F because enthalpy of the feed is H F plus Q W which is heat given to the reboiler Q W would be equal to D H D over here plus W H W that is here. And the heat which is taken off it is Q C over here.

(Refer Slide Time: 44:27)



So, the total material balance and component balance we can substitute for F from equation 17 in equation 18. So, if we substitute this F that is D plus W over here. So, you will obtain D plus W z F would be equal to D x D plus W x W.

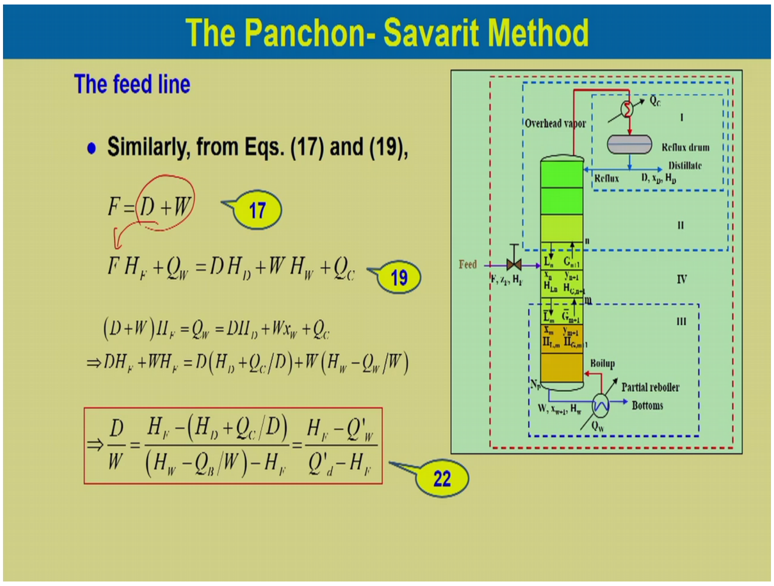
(Refer Slide Time: 44:55)



Now, x D denote the reflux or the distillate concentration. And these may be sub cooled liquids. So, the notation is used x D and we can write D by W from this equation 20 would be equal to z F minus x W divided by z D minus z F.

So, in place of x D know you substituted with z D. So, over here.

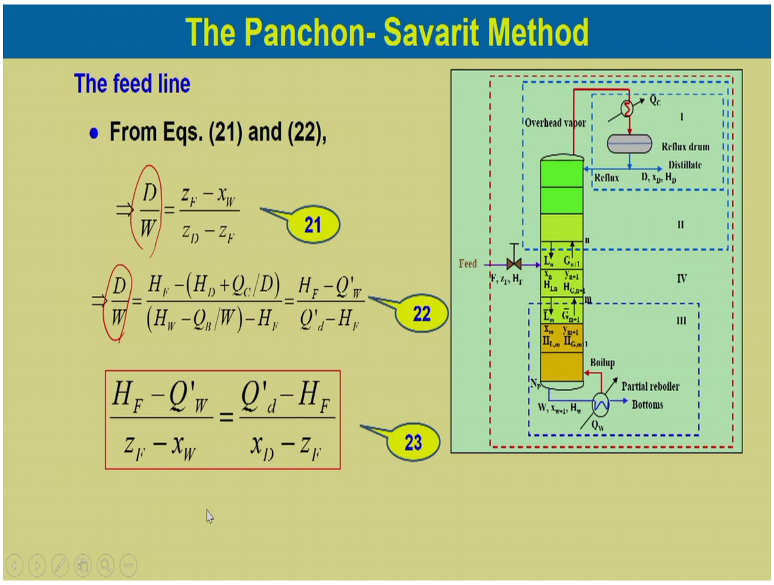
(Refer Slide Time: 45:35)



So, similarly from equation 17 and 19, we can write F 17 is this one the total material balance and the 19 is the energy balance equation and just if we substitute F over here. So, and then rearrange we would obtain D by W would be equal to H F minus H D plus Q C by D divided by H W minus Q B by W.

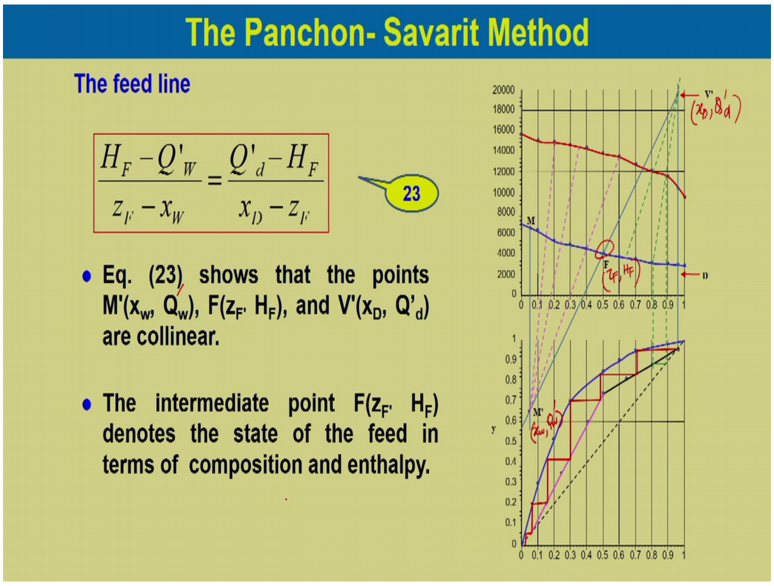
So, this would be equal to H F minus Q W dash divided by Q d dash minus H f.

(Refer Slide Time: 46:37)



So, from equation 21 and 22 we can write. So, we can equate this 2 and we can write H F minus Q W dash divided by z F minus x W would be equal to Q d dash minus H F divided by x D minus z f. So, this is equation 23. This is the equation considering the overall fractionator including feed distillate and bottoms. Now we have for all the 6 sense we can draw the operating line for stripping section as well as rectifying section.

(Refer Slide Time: 47:31)

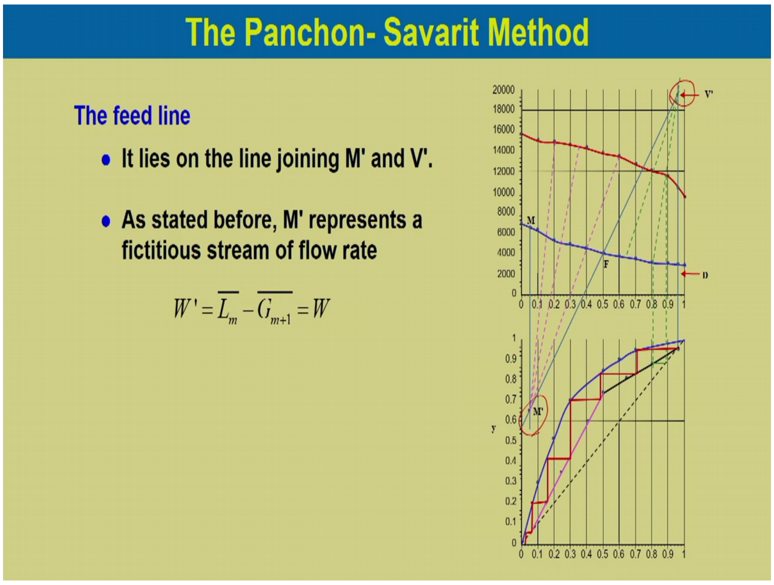


And we can now draw or find out the significance of the feed line. Equation 23 shows that the points M dash that is x W Q W dash and feed z F H F and V dash x D Q d dash.

So, this is x W Q W dash. This is know feed point is z F H F. And this is x D and Q d dash. So, these 3 points M dash F and V dash are collinear from this equation following the argument of the rectifying section and then stripping section we have done before.

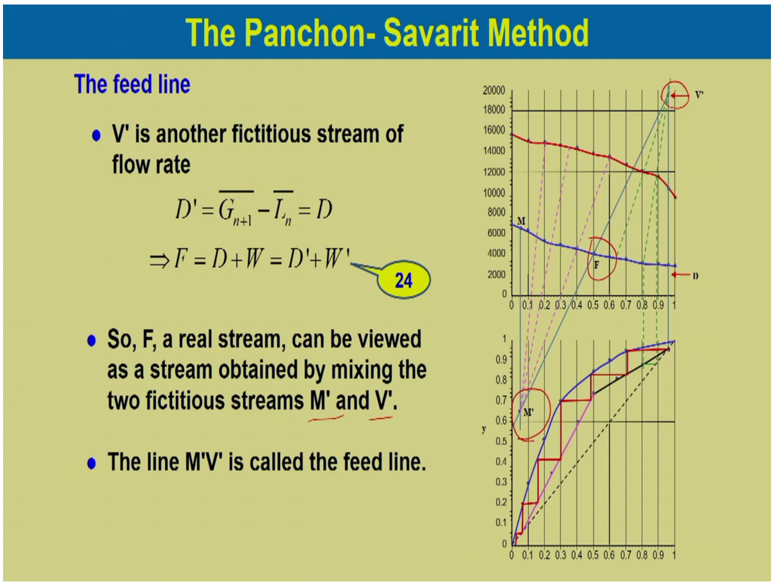
So, the intermediate point which is F z, F and having the coordinates z F H F denotes the state of the feed in terms of the composition and enthalpy.

(Refer Slide Time: 49:07)



So, it lies on the line joining M dash and V dash. So, this is know M dash and this is V dash. As stated before M dash represent a fictitious stream of flow rate W dash which is equal to L m bar minus G m plus 1 bar which is equal to W.

(Refer Slide Time: 49:35)



So, V dash is another fictitious stream of flow rate D dash is equal to G n plus 1 bar minus L n bar which is equal to D. And F we can write from the total material balance then F would be D plus W.

So, which would be equal to D dash plus W dash. So, F a real stream can be viewed as a stream obtained by mixing the 2 fictitious streams that is M dash and V dash. So, this F can be viewed as a mixture of M dash and V dash 2 different know streams. That is 2 fictitious streams mixing together to obtain F a real stream.

The line M dash V dash is called. So, with the line joining M dash V dash intersecting F is called the feed line. So, this distinguish between the trays required between the stripping section and the rectifying section. So, thank you for hearing this lecture. And we will continue our discussion on the Ponchon and Savarit method in the next class.