

Mass Transfer II
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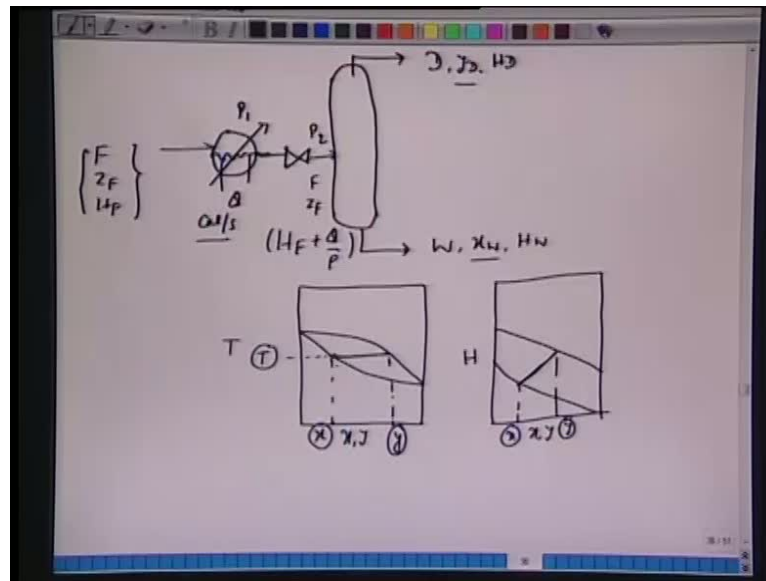
Lecture. # 16

In the previous lecture, we discussed single stage flash drum in which we had a feed pressurize to certain pressure high temperature. Then, it was flashed and then we had this separation between vapor and liquid phases. And then, we drew this $T \times y$ diagram, we have the projection on $H \times y$ diagram, we wrote this species balance, material balance and enthalpy balance, to show that how the tie line on $T \times y$ diagram does is equivalent to the tie line on this $H \times y$ diagram. And sincerely, we marked this salient features on these diagrams, $H \times y$ or $T \times y$ diagram. And we also said that, one can apply the mixing rule, between the two streams; two leaving streams, which are in equilibrium vapor in the liquid to show that, the feed also lies on the straight line lying between vapor and liquid.

So in that example of that short discussion we had in the earlier lecture, we said that, this flash drum or is equivalent to an ideal stage of a distillation column, in which two leaving streams can be assumed to be in equilibrium. In other words, if we give enough resistance time or and we have enough mixing, good mixing between the two phases vapor and liquid. Then we can assume that, the two leaving streams are in equilibrium and $y \times x$ or $H \times x$, $H \times y$ they will fire, they will lie on this tie line. But very often it happens that, the two leaving streams are not in equilibrium. So in that case it is also important that we understand, what happens to the tie line, what is the moment of this tie line, as a two leaving steams are not in equilibrium.

So we continue with the discussion, we will have a qualitative discussion of this non-equilibrium on $T \times y$, as shown in $T \times y$ and as shown on this, enthalpy $H \times y$ diagram.

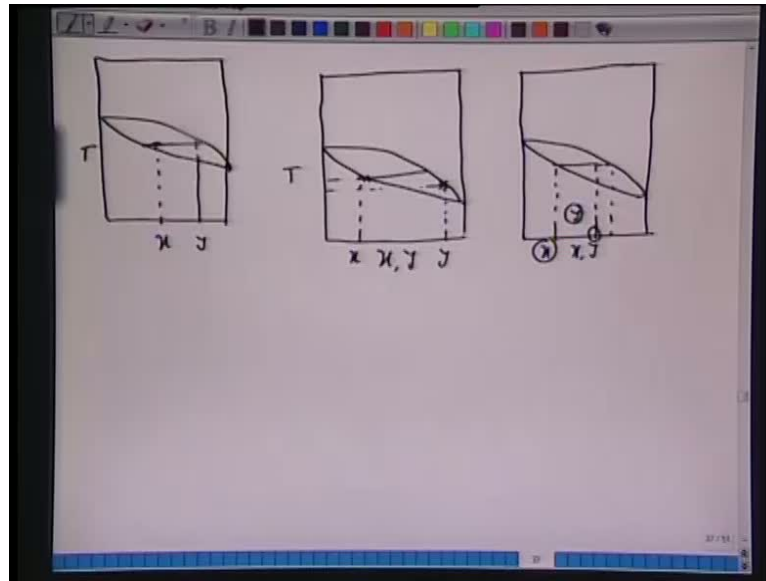
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Just recall, we had this flash drum and we had this feed, F , z_F , H_f . It was brought in this is brought to heater; we had this heating load Q certain pressure P_1 . And then, it was throttle or flashed to this pressure P_2 , so the molar flow rate remains the same, z_F remains the same. Except now, the enthalpy of this liquid is H_F plus Q , this Q is in calorie per second and you can have H_F by F . So H_F by F , we can have H_F , we have calorie per mole plus Q by P . So Q is nothing but calorie per second heating rate here. And then, we have this vapor leaving D , y_D , H_D and we have this, liquid leaving here **flow rate was W** molar flow rate W , we have x_W and we have this H_W . We said that, this L vapor here and the liquid they would be in equilibrium, if you allow for good mixing and sufficient residence time.

If that is equilibrium, we can have this T vs x vs y diagram and the coordinates of this y and x , they will lie on this tie line or we have this horizontal straight line prospering to this temperature T , at which and the liquid composition; saturated liquid composition is x and saturated vapor composition is y . So, it is an equilibrium, and if you take this projection on H vs x vs y diagram, then we showed that, we have this x vs y and we have H , liquid enthalpy and liquid vapor and then corresponding to these two points, we have this tie line, which is y here and x here for the same mole fraction, they appear. And there is a tie line on this H vs x vs y diagram; this is a tie line on this T vs x vs y diagram.

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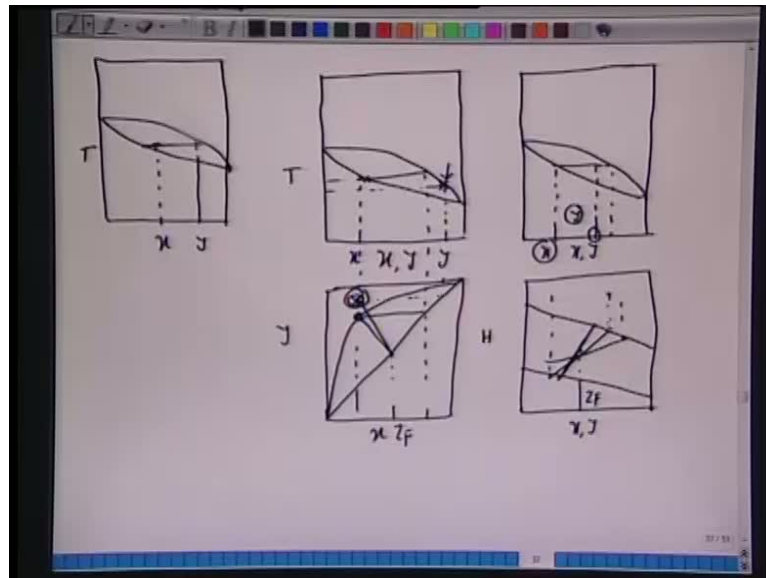
Now what happens, if these two leaving streams they are not in equilibrium? Now in these cases, we can have several cases. So, if we have two streams leaving liquid and vapor not in equilibrium, then let us see, what scenarios we can have. So, we have this T x y diagram, now the one thing that can happen that the vapor and the liquid, they may not be at the same temperature. In other words, we have this mole fraction given x here at this temperature T_1 , but vapor may be slightly smaller than the temperature that would have been at the tie line. So instead of this, now we have this kind of situations.

Also we can have equilibrium where it is possible that, temperature is the same for liquid and vapor, but the compositions are different. In other words, we can have this situation like this, in which the composition of liquid is x or the composition of vapor may be slightly smaller than this. So, these are different scenarios of non-equilibriums. In one case, we can also have the other way round, when the coordinates for the vapor phase lies on the saturated, this due point like this. This is your y , but the liquid mole fraction is slightly smaller than, what would have been at this under equilibrium, instead of this, now we have these situations.

So, in other words, we can have all types of scenarios. For this non-equilibrium, two leaving streams not at the same temperature. So on the tie lines; we do not have this horizontal straight line. Now, vapor is here or liquid is here and vapor is here or this could be other one, there is some difference in temperature between the two leaving

streams. Now the same as the flash drum temperatures or in some cases it is possible that, we have the same temperature, but y and x , they do not correspond to this tie lines. Maybe mole fractions in the liquid phases, slightly larger or maybe the vapor phases slightly smaller etcetera; we can have several of this non-equilibrium condition. In the case of non-equilibrium conditions, then it is very important that we understand, that when we take the projection on $H \times y$, then what line we will get, it would not be a tie line either.

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So, we draw this $T \times y$ diagram or we draw $x \times y$ diagram equivalent to this non-equilibrium conditions. So, if you have y and x and recall, we took this 45 degree line then, we take this projection of x here like this and we take this y like this. So, we have this y here and then, this line will fall on this equilibrium curve $y \times x \times y$ diagram. However, if we have this non-equilibrium, that means the temperatures are different. Then you can see that, when you go down to this and when you come here, then it is possible that at this point will not lie on this equilibrium.

Similarly, we have this feed line, if you recall that earlier we had this Z_F . Now, we have Z_F here and now, for the equilibrium curve and if there is non-equilibrium then, we can have this tie lines straightly moved away from this. Similarly, if you plot, $H \times y$ diagram, so if you plot $H \times y$ diagram like this, like this here and to recall, we took the projection for y , we took the projection for x , we have this $x \times y$ on this tie line. But again, if mole

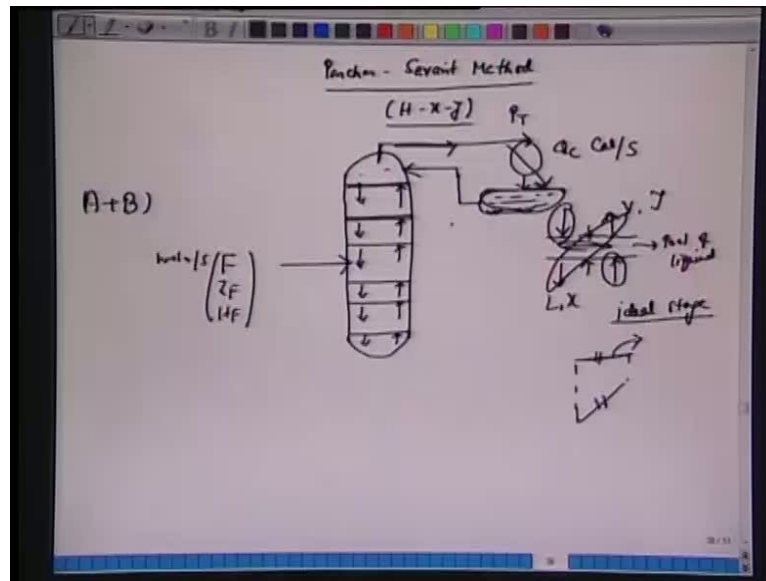
fraction is different or mole fraction is same, but the temperature is different, then one can show that this feed Z_F , which we have here it is possible that, we have different conditions like this or we can have the conditions like this.

So, in either case it is possible that, what line we obtain by taking the projection from here and x , they will not be a tie line. In other words, this point will not lie on this equilibrium curve. So these are the different things, which we have to remember for equilibrium conditions and for non-equilibrium conditions. Now what we do, we start the second topic; that is a distillation column. So, what we have done so far, T x y diagram and H x y diagram just in case of absorptions, we establish the thermodynamics solubility diagram. So now, we have this equilibrium vapor liquid equilibrium as to mean now, we have the two leaving streams are in equilibrium itself here. Now, after that we started this flash drum, we said the flash drum is nothing but a model; this would be a founding stone for our design of a distillation column.

So in that case, if you have one stage then two streams, they come to that stage, they mixed well-mix and then they leave. So, the leaving streams can be assumed to be in equilibrium, if we talk of ideal stage etcetera. So now we take up this, design of a distillation column or how do we get number of trays required for achieving certain degree of separations, either in the vapor or in the liquid phase? Now they are two different approaches, one approach is based on T x y or y x for a given temperature. And the second approach is based on H x y , if we recall that, we said that, once you fix the temperature mole fraction x and y then enthalpy is fixed. In other words, two methods are more or less identical, so approaches are different. In one case you work on enthalpy, we do enthalpy calculations.

And in other case, you work on mole fractions x and y balance, both of them should give the similar answers, to find out how many number of stages we required. One method is called Ponchon-Savarit method; H x y and the second method which is based on, mole fraction T x y diagram and that is called McCabe-Thiele method. McCabe-Thiele method is more popular more convenient to use, but there is a very **restrict** restriction or assumptions; one has in this McCabe-Thiele methods. Enthalpy H x y methods is more cumbersome mathematically or calculations graphically, but it is more regress. So, we start with H x y diagram, which is based on Ponchon-Savarit method to determine, the number of stages at distillation column.

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So we have this method here, which is Ponchon-Savarit method, so we are going to work on this, H-x-y diagram. And we said although this method is cumbersome, but it is more regress than the other methods. So, what is the distillation column schematically? The way we drew for absorption column, we have a tower like this vertical towers and there are trays. So there are several trays, like this and we have a feed here. So we have several trays, feed is brought here. So say the molar flow rate of F, feed is F moles per second, we have the mole fractions Z_F . Again let us focus on binary components, A plus B and we have the enthalpy, given as calorie per mole.

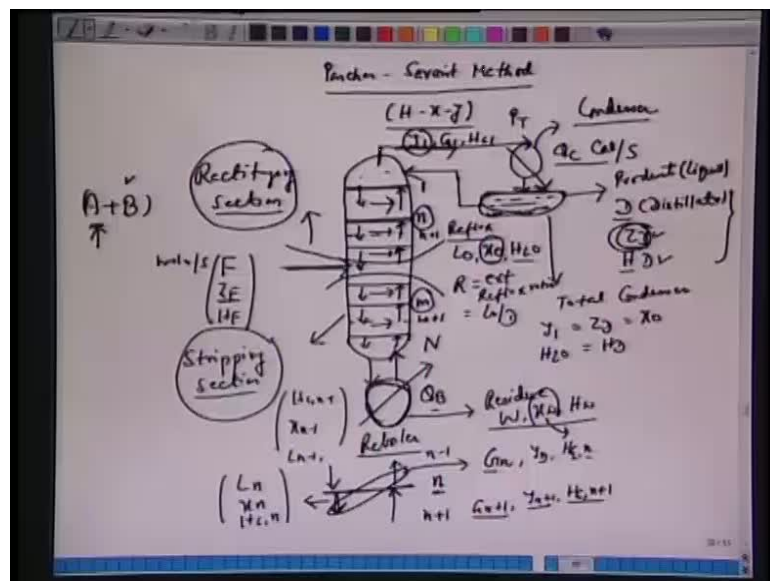
So this is a coordinate of your feed, this feed is brought into this distillation column, so the pressure is fixed at P T. Now, at every stage if you look at, they are several stages like this. If you look at every distillate stages, what physically scenario we will have? Liquid will trickle from the top, we will go like this. So there is a pool of liquid **pool of liquid**, and the vapor it will go through this. So there is certain layer of this liquid, in which incoming liquid and incoming vapor; they are allow to come and well-mixed here. Then the leaving stream is a vapor here, and the leaving stream is liquid. Now if you recall, our you know discussion on this flash diagram. If it is an ideal stage, which means we have the equilibrium between vapor and liquid.

And if the mole fraction is y here and the mole fraction is x here, then this y and x will lie on this T x y horizontal tie line or in this case of H x y diagram, if we recall, it will lie

on this tie line. So, both are the tie lines, if they are in equilibrium. For this chapter, we assume that each tray stage or trays, they are ideal stages. Now this vapor this feed gets in, it has a certain mole fractions it now you can take a several there are several trays here. Then you can draw each stage, the vapor is leaving and we have the liquid getting trickling from the top. Now, let us concentrate on the top phase. When the vapor leaves here, then this vapor is taken outside, we have a condenser here, vapor is condensed.

So, there is a condenser load drawn by this, downward pointing arrows to show that, certain calorie per second is released from the system. So, the stream which comes out from here, it is condensing here then, we have a separator or we have some storage here, we will discuss about this. So liquid here so, let us say this entire vapor is now condense into this liquid. Then part of this liquid, is brought back to this distillation column and that is the liquid, which you see here trickling down. So, there is a reflux and part of the liquid is your product, so this is the product.

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Let us erase this. So, we have feed F and we have the top product, which we call it D for distillate. So this distillate, will also have composition Z_D and we it has enthalpy. Reflux is liquid, we call it L_0 , denote by L_0 , it will also have the mole fraction X_{L_0} and the enthalpy is H_0 . Now notice here, if entire vapor is condensing to liquid. Then, the compositions x_0 , Z_D and the compositions of the vapor, which is arriving from here y_1 flow rate G_1 , enthalpy H_{L_1} , y_1 , x_0 and Z_D will be the same. Enthalpy H_D will also

be same as $H_L 0$, and these enthalpies will differ from $H_L 1$ by this Q_C calorie per second. So this is what we call it, total condenser.

In the total condenser, we have y_1 same as Z_D and same as x_0 , because entire vapor is now condensed, so the mole fraction does not change. And the enthalpy of reflux liquid, which goes back to the distillation column, is same as the enthalpy of the leaving liquid product, so this product is liquid. Now, let us talk about the certain nomenclatures here. Generally, we follow the number of plates we give the counting starting from the top. So we have this one here, top plate is one then, we can have two, three etcetera and say we have n here. Similarly, $1, n, n+1$ and this will continue like this, we can have m . We can have somewhere say, $m+1$ similarly; we can have this $n+1$. Another plate here and the top plate; bottom plate is n , so there are total number of plates are n here, 1 to $n, 1, 2, 3, 4, n, n+1$. Then we have $m, m+1$ and finally, we have this n here.

There is a reason why, we have given the two different nomenclatures n and m . actually, and the sections ever feed from here, so this is called as rectifying sections. So, this is rectifying sections, why rectifying? You know of course we can make out the feed, the one which is one component out of A plus B which is more volatile; the vapor will become rich in A . So, we are saying that, this stream is getting rectified, this steam is getting purer and purer. So product Z_D as mole fractions much larger than, what we have Z_F for component A , which is more volatile.

Similarly, the liquid which trickles from the down will become richer and richer in other components B . So section just below F , this is called as stripping section two together is distillation column. Now let us see what happens to the liquid, liquid which leaves from here, now it comes to a re-boiler. Here, we are giving the heat and call it Q_B , so notice this Q_B and Q_C , this is a condenser. And now we have this Q boiler, where this liquid is vaporized and vapor send back to part of the vapor part of the product, stream feed is sent back to this column as a reflux. And we withdraw this liquid part of the liquid here as a bottom product, which we call it the residue. So W, x_W, H_W , similar to, we have distillate D, Z_D say X_D . So essentially, we have a distillation column consisting of two parts, rectifying section and stripping sections underneath F and above F . We have a condenser, where we take the top product vapor condense take out the product, part of the product is send back to the distillation column call as, known as reflux .

In there is stripping sections, we said the liquid is getting richer and richer in A. So the product x_W , will have the mole fractions A, which will much smaller than what we have A or the mole fraction of B, $1 - x_W$, which will much larger than this B. So essentially, we have a stripped A from here and we have transferring into this vapor phase. So, we have rectifying sections and we have this, stripping sections.

Reflux R is defined just call, external reflux or reflux ratios. This is defined as L_0 over D. So if we withdraw, 100 moles per second and send back say 20, then reflux ratio is 20 by 100. So you know that, the ratios of molar flow rates of L_0 and D that is one thing. Here we have the re-boiler, we are giving the heat here and then, we withdraw this liquid product here. And we have this part of the liquid is vaporized to send back as a reflux. So, we have the liquid reflux here and we have this vapor reflux here.

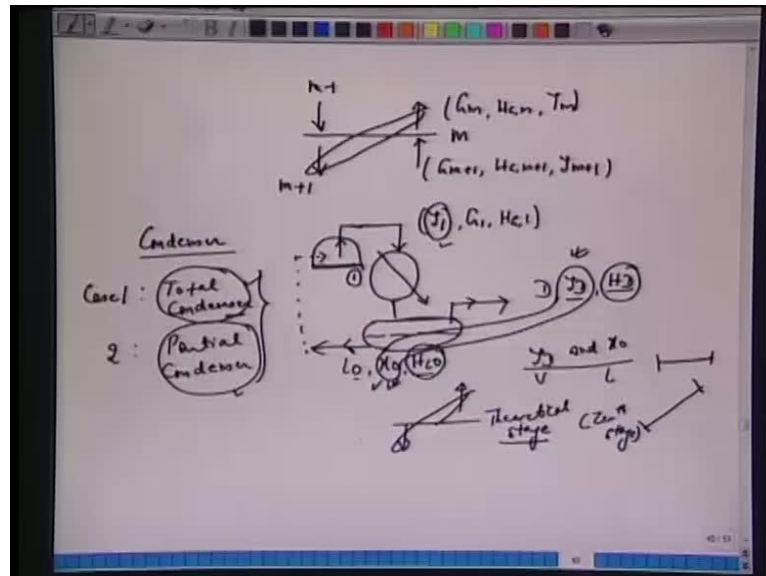
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Now, we should also have this nomenclature G, so let us look at, one stream one plate say n. So notice the difference, that we are using m for stripping sections and n for rectifying sections. So n represents, a general plate number n counted from the top 1, 2, 4, 5 nth and we are counting it n, n plus 1 say, 46, 47 m and plus 1. So if you look at n, that means we are looking at a stage. A general stage in rectifying sections, where we have vapor stream, which comes from n minus n plus 1 stream, because we are counting from here. So the vapor, which arrives at n, comes from n plus 1 and this vapor n, it goes to n minus one plate. Liquid this comes from here that is from L minus 1, it comes to the nth plate and it goes to your n plus one th plate.

We give the nomenclatures here L, this liquid which leaves form nth plate, it is L_n . Vapor which leaves from nth plate, is called is given the nomenclatures G_n . So, G_n and L_n they are equilibriums. This would be L_{n-1} ; this would be G_{n+1} . So, G_n and we have y_n , then we follow this and we will call it H_{G_n} . We have G_{n+1} , y_{n+1} , and $H_{G_{n+1}}$. So the convention, we are following that the streams are tagged with respect to this plate they originate. So, this vapor originates from here this nth plate, so it has G_n , y_n , H_{G_n} here. This vapor originates from the bottom plate just underneath this n plus 1, so it gets nomenclature G_{n+1} , y_{n+1} , $H_{G_{n+1}}$. The liquid which originates from this n plate, the leaving it is L_n , x_n and we have H_{L_n} .

And the liquid just give up this is L_{n-1} , you can write x_{n-1} , or you can write $H_{L_{n-1}}$. So these are nomenclatures, we are following here.

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You can also take a plate just for continuing our discussions, plate number m . So, which means this vapor, which is arriving here, will have the nomenclatures given as, G_{m+1} , H_{m+1} and we have y_m , y_{m+1} . Similarly, this would be G_m , H_m , and y_m , G stands for gas or vapor. So, that is the conventions, we have for this and so far, we can have the argument for the liquid streams, which trickles or falls from the $m-1$ stage and leaves to this $m+1$ stage, again these two streams are in equilibrium. what we do here? We talked about this condenser, so before we do some more calculations. Let us concentrate on one more condensers one more time, on this condenser.

What we described in the previous slide or the previous page here. We talked we said that, the vapor which arrives from here the top. So, notice that, this composition is again y_1 why? Because, the top plate is the first plate one. So the vapor, which leaves from this originate from this plate, is y_1 , molar flow rate is G_1 , mole fractions or enthalpy is given as H_{G_1} . Now we are condensing it here, we said that in the previous case entire vapor was condensed. So that is the case one we should write; we should make a note that, case one we have total condenser, so, we condense, the entire vapor.

As your consequence, if you recall and revisit the page, the leaving product, the liquid and leaving the reflux, which goes to the column has a same compositions, because we have just condense the compositions will remain the same here. Now, the case two or the arrangement two is partial condenser. So, a typical distillation column can be run in either of the two modes. So, we understand that, what happens in the partial condenser. Now when we have the partial condenser, the way we draw this schematic here, that now we condense partially, which means this vapor some products are still left out. So now notice this here we call it, still this is D distillate, but now the mole fraction is y_D instead of x_D . Why? Because, it is a vapor phase and the enthalpy is H_D .

The liquid which is condense now, this goes back as a reflux notice; this is molar flow rate is L_0 . Why 0 ? Because the top plate is one and this plate is actually, zeroth plate outside the distillation column. So, this reflux will go back to this column top of this plate. So this comes from one plate evaporate this, we will talk about the continues so this is L_0 , mole fraction is x_0 and enthalpy is H_{L_0} . Now notice here, that this vapor and liquid the two leaving streams, can be assumed to be in equilibrium, so see the difference. In the earlier case when we have the total condenser, this Z_D or y_D or x_D it was same as x_0 , but here y_D and x_D , present equilibrium mole fractions, vapor, and the liquid. So you can think that, on $T-x-y$ diagram; they will lie on this tie line, on this $H-x-y$ diagram; they will lie on this tie line.

So, in the partial condenser mole leaving mole fractions of distillate D is in equilibrium with the reflux, the total condenser two compositions are the same. H_D and H_{L_0} , it is a saturated vapor enthalpy and it is saturated vapor liquid. And also notice that here y_1 will not be same as y_D or x_0 . One has to make this is species balance to find out, how y_1 is related to y_D and x_0 ? So it is very important that we understand, what happens to the leaving stream, compositions enthalpy, and the vapor in case of total condenser and the partial condensers. So this here we have, two leaving streams in equilibrium so actually this condenser, can also be considered as a theoretical stage. In case of partial condenser, because two leaving streams are in equilibrium and we call it zeroth stage. So, in addition to all these nomenclatures and conventions which we are using here, we also important understand that mole fractions y_D and x_0 , they are not the same.

So, now let us just summaries qualitatively. We have a distillation column, so it is a vertical column, it consists of several plates. These are; we will talk about in subsequent

lectures, plates or you can go through the text book to see that, plates are nothing but it has sieves it has sieve plates. The different type of configurations mostly our discussion can be will confine with the sieve plates. So, we have the plates, circular distillation column plates like this and there are holes on this on these sieve plates. So, the idea is the vapor will flow through the plate then will pool of the liquid, so vapor will essentially bubble through this pool of the liquid. Liquid head is maintained constant, with the help of a down command etcetera and the liquid falls from the top.

So, entire distillation columns let us say there are several of plates feed enter at some locations, not necessarily at the middle of the distillation column. Feed can be inserted or it can be it can enter into the column much below the midpoint. We will talk about this, when we take up the design, where is the entry point of the feed. So feed has certain compositions say 30 40, 30 70 and we want to enrich 30 to say 90 for A and the bottom product reach in D 70 to 90 that is possible. So, one enthalpy; one feed molar flow rates; mole fractions brought into this distillation column, there is vaporization at every stage.

Vapor which enters on the pool of the liquid, meets with a different a liquid which is non-equilibrium they mix, they spend some distance time, then the vapor leaving and the liquid leaving we can assume that to be equilibrium, if it is a ideal stage. Now vapor leaves from the top column, top plate, it goes to a partial or total condenser. So, we have condenser, where we extract the heat, so enthalpy is reduced there. If there is a total condenser, then the mole fractions leaving from the top plate and the mole fraction of the product and the mole fraction of the reflux will all be the same, enthalpy will be different.

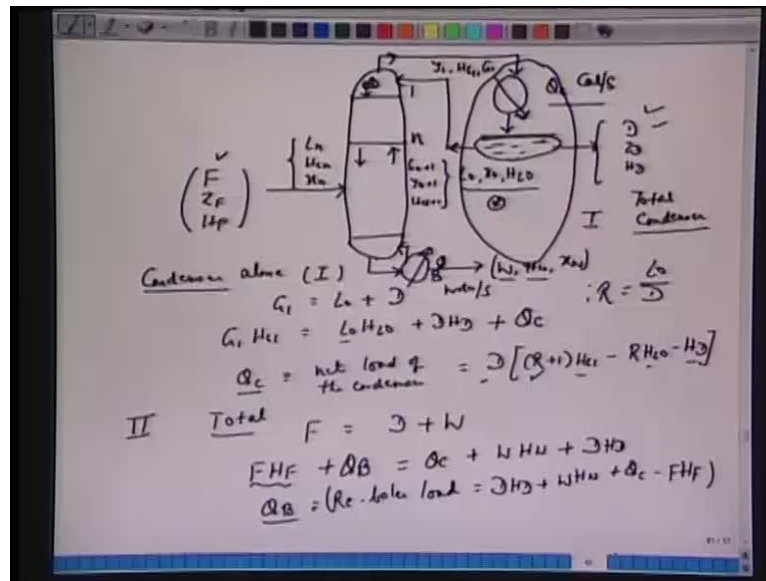
Enthalpy of the leaving product and the reflux will be the same again, but it will be different from the incoming vapor phase to the condenser and they will differ by this condenser liquid. So, these all section ever feed, we call it rectifying sections. And the sections just underneath feed, we call it stripping sections. We discuss why? Now the liquid gets trickles down, flows down comes to a re-boiler, because we have to send the reflux back again to the column. So, the part of this liquid, which we draw as a product, what product we want W , moles per second and part of this liquid is vaporized and send back to this column. Again, we have this, q_b this heat goes into the system. So, certain heat is removed Q_c of the condenser and certain heat, it is into the system. So, there is a

temperature gradient and think that temperature will be larger by intuitions at the bottom and slowly, slowly this will decrease.

Hydrodynamically pressure will also change in the distillation column, because vapor and the liquid, they have exit path. Vapor has to overcome the hydrodynamics resistance liquid of course, falls through by this hydrodynamic. But for our design calculations we assume that, pressure more or less remains the same. In other words, we make use of the fact, that given pressure; distillation pressure whether atmospheric or larger than atmosphere $T \times y$ diagram and $H \times y$ diagram are available to us. So this is about the introductions, to the distillation column we understand the meaning of this reflux, there is an external reflux ratios inside certain part of the liquid gets inside. So we have L_0 by D external reflection ratios, how much amount of total product is brought back?

There are some cases, where the entire total reflux is a 100 percent. So those are very extreme cases, but so far let us be familiar with our conventions of G , L , M , N stripping column, rectifying column, reflux ratios, partial condenser, total condensers. Before we make a species balance, enthalpy balance on several, several envelop. So we will take a curt section above the feed, all the way till the condenser. You will take another section, just underneath the feed all the way till the boiler will make this energy balance, will make this species balance. And we will see that, how we can track the coordinates of the mole fractions or we can track the locus of this mole fraction in the vapor phase and the liquid phase, as the vapor flows up and the liquid flows down.

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So, let us make enthalpy balance, species balance, material balance on certain section of the distillation column. We will have to take several envelopes. So, before that, let us redraw this distillation column again. So, very quickly we have this distillation column, let us mark the top plate, which is one and just mark the n th plate, which is N vapor will be drawn from here. Let us have total condenser, the simpler one; we have Q_c , condenser load calorie per second is withdrawn. We have this separator and we withdraw this product or distillate D , Z_D , H_D we have the reflux L_0 , x_0 , H_{L0} and it goes back to this distillation column.

So, we have y_1 , H_{G1} , and we have G_1 because all of them this vapor comes from this top plate. Similarly at the n th, you can have this G_{N+1} , y_{N+1} , H_{N+1} . And this liquid which comes from here, is L_N , H_{LN} and we have this x_N . And this liquid the reflux this liquid composition and the state is same as this status as same as the reflux. So, now let us make, a balance on this condenser. So we will write the balance equation, what is condenser? So, if we look at, maybe we have taken the envelope like this, we call it 1. So condenser alone 1, you can see G_1 equal to L_0 plus T . We just make a note for our understanding that, this is a total condenser, we discussed about this just a minute ago.

So we have total condenser, G_1 equal to L_0 plus T , this is a moles per second and we have G_1 , H_{G1} incoming enthalpy equal to L_0 , H_{L0} . So this is the liquid, which goes

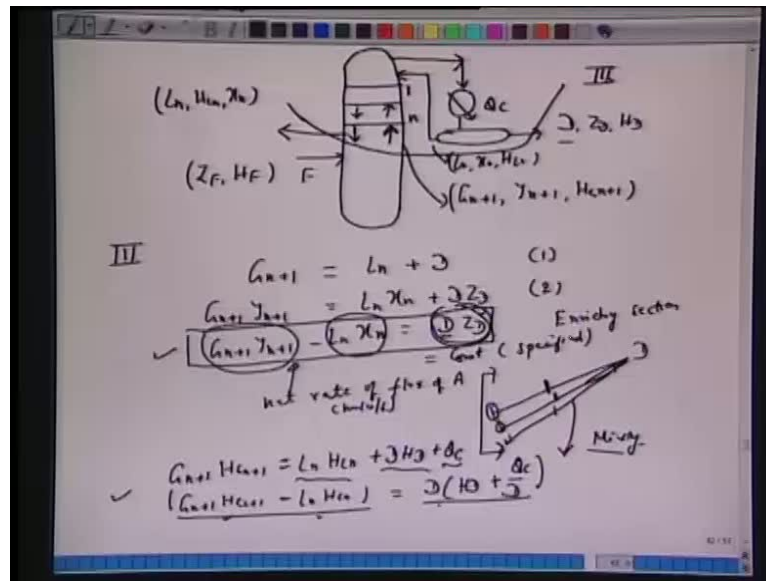
back to the distillation column as a reflux from this separator. So L_0 plus H_{L_0} plus, we have D , H_D , H_D and plus, make a note: we have this Q_c , calorie per second the heat load on this condenser. So, this is enthalpy balance. We can write now Q_c as, net load of the condenser as D . So, we are just trying to rearrange this $R + 1$, $H_{G_1} - R$, $H_{L_0} - H_D$. So, all we have done, we have made use of this fact that; reflux ratio as we define earlier, is L_0 by D .

So, we have replaced L_0 , R/D as an exercise, you can convince yourself that we can calculate, the net load of heat if you know the reflux ratios. What is the product out here D and the enthalpy of the different streams H_D , H_{L_0} etcetera and one can calculate the net load of the condenser. So that is one. Let us make balance on two; which is, it says total. So to do that recall, we have the vapor liquid which goes out here. It is complete this we have this now, Q_B heating load and we have the vapor which goes back to this, if the bottom product as W , we have H_W and we have this H_W . So we have feed, entering here F , X_F or Z_F .

And the reason why, we write Z_F is? Z_F could be X_F , if the feed is liquid or this could be Y_F , if feed is vapor or this could be combination of liquid and vapor. So all possibilities are here, we writing F in general, Z_F and we have this H_F . So, this is the coordinate or just picks these are the picks of entering feed here. We have W , x_W , x_W ; x_W heating load is Q_B here. So, now we will make a total balance, we can also write F equals D plus B . So feed here, D here and we have now this W or we can call it B . So, let us change this to B , so we have F W plus B . Heat load enthalpy balance, if you make energy balance F , H_F incoming enthalpy plus we have this load of Q_B ; we are supplying this Q_B into this re-boiler to vaporize this, vapor to this distillation column.

So we have F , H_F plus Q_B , this will equal to all heat plates which are all heat streams, which are leaving in the distillation column including this Q_C plus W , H_W , H_W plus D , H_D , H_D which means, Q_B now we can write as re-boiler load, equivalent to this Q_C calculations. We have this Q_B re-boiler load, as D , H_D plus W , H_W plus Q_C minus F , H_F . So, we have come out with this expression for, Q_C and Q_B by very simply taking this total energy balance. Let us do one more time, so let us redraw this distillation column again here.

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We have the vapor which leaves here, this condensed then we have this separator. We draw this product D, Z D, X D; this goes back to this top of this distillation column first plate is one. So we have this L 0, x 0, H L 0 and we have this Q C as heating load, heat enters here F with Z F and H F, as a specification. Let us take n th stage and make a balance like this. This is the envelop 3, so we had one for the condenser, two we made, for the total column and third is for, the condenser. Now, this vapor which arrives here is G n plus 1, we have y n plus 1 and we have this H G n plus 1. The liquid which leaves the plate is L n, H L n and x n.

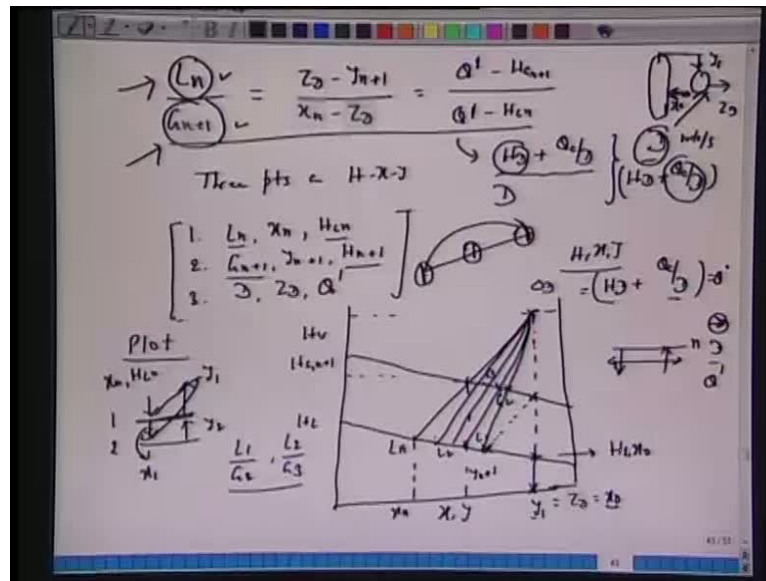
So we can write, G n plus 1 incoming stream, molar flow rate will be L n outgoing stream plus product D that is one. Similarly, we can write G n plus 1, y n plus 1 equals L n, x n plus D, Z D this is two, which can also be rearranged as, G n plus 1, y n plus 1 minus L n, x n equals D into Z D so you notice, there is a reason why we have written like this, see these are the general expressions for any stage in enriching section, so we have taken this envelop just underneath this nth plate, where we can write the G n plus 1, y n plus 1 incoming minus out going for any plate from 1 to n in the energy section equals the output, which is a constant D into Z D constant the same that, this is specified. Once we specified the quality of the feed; quality of the product distillate and the molar flow rates.

The difference between the two streams anywhere choose any stage, make a note that, this minus this is a constant here, we call it net rate of flux of A. So it is a net rate of flux of A, moles per second and the reason that why we writing like this, if we recall that now we can apply this mixing rule, since D is fixed all it means, for any stage in the emerging sections. If you apply this mixing rule on this H x y diagram, all of this will be intersecting at one point. In other words, if we take this vapor and recall we extract this liquid, we will get this D. On the second stage; if you take vapor, extract this liquid you will get this D, we will come back to this.

Whatever we have learned for a single stage, in drawing those operating lines, one can also make use of this, that the difference between the two molar flow rates at any stage at any stage of the column remains the same as D, Z D. We can do the same thing for the enthalpy, $G_{n+1} - H_{n+1} = L_n - H_n + D$, $H_n + D = G_n + Q_c$, so, the incoming enthalpy, equal to three outgoing energy calorie percent, one is with the liquid, one is with product, and one is this Q_c . Again we can rearrange, to write that difference $G_{n+1} - L_n - H_n$ is constant as $D - H_n$ saturated enthalpy of the leaving product plus Q_c by D.

So, we have the similar situations of this mixing equilibrium, for any stage either you make a species balance or you make an enthalpy balance. The difference between the two streams, vapor and the liquid is a constant D, Z D and D, $H_n + D = G_n + Q_c$ by D and this is very useful that, we understand this, that when we do the calculation graphically when we represent, we understand that coordinates of one, two, three will be on the same straight line because of the mixing rules.

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We also; we can rearrange to show that, now we have L_n over G_{n+1} , the same instance we are saying that, L_n over G_{n+1} can be written as Z_D minus y_{n+1} over x_n minus Z_D equals Q' prime minus H_{n+1} over Q' prime minus H_n , so this Q' prime now, we are defining as H_D plus Q_c by D . Now let us try to understand, what it is? Leaving stream has the enthalpy only H_D , with the molar flow rate D all we are saying that, now there is hypothetical stream was molar flow rate is still the D moles per second, what is enthalpy is actually H_D plus Q_c by D , so we have a hypothetical stream, leaving this distillation column or this condenser. The molar flow rate is still the D , but it leaves with enthalpy Q_c by D , we will make use of this to mark this point corresponding to this Q' prime here.

The idea of doing this is same here that we have three points, if you want to mark on $H-x-y$ diagram; one is L_n with species, with concern mole fraction x_n , H_{L_n} . Second stream is, G_{n+1} , y_{n+1} , H_{n+1} and the third stream is, D with the mole fractions Z_D and enthalpy is Q' prime, which we defined here as Q_c by D plus H_D . These three points for any tray one to n , in a stripping; in rectifying section will lie on one straight line, because this what we have done in case of x_n this D is nothing but difference of L_n and G_{n+1} similarly, this difference of the two enthalpy H_{L_n} , and H_{n+1} , we can show that, this is Q' prime we multiplied by this molar flow rates.

So, if we mark these points on $H \times y$ diagram, these three will be on the straight line, as if from this point if we subtract so much of enthalpy, we get this or in this liquid if you add so much of enthalpy we will get this, if you add so much of enthalpy, total energy we will get this points, so all about mixing rule, which we have discussed earlier. We would like to plot this, before we end here. So, one can plot this, $H \times y$ diagram, we have this H_L and we have this H_V , so what we have L_n over G_{n+1} ? It is $Q' - H$, mark this point and call it. Let us call it ΔD . Now, look at the mole fractions here. This mole fraction, starting from the end we have this y_1 , mole fractions of this stream leaving the distillation column is y_1 , is condense completely, so we have ZD and send back as a reflux, which we have x_0 .

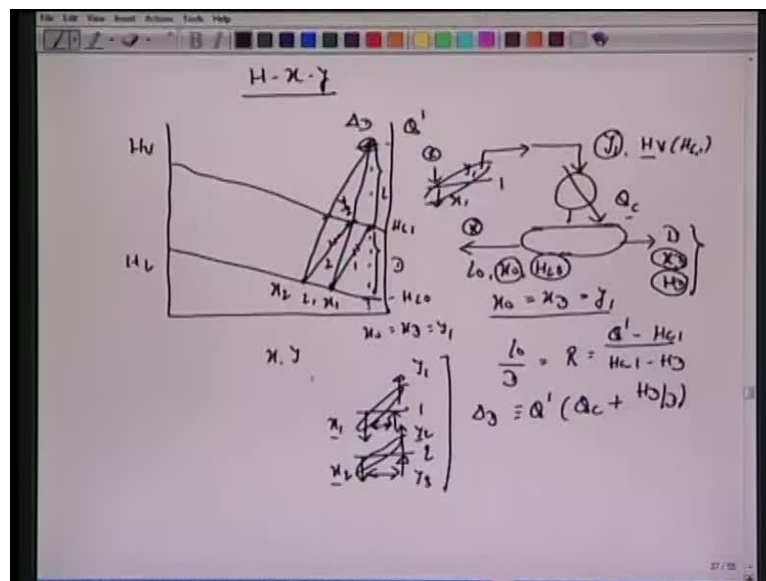
Since a total condenser, this y_1 will be same as ZD will be same as x_0 . If this distillate or reflux is saturated, then you can see that, this line will fall here, we will call it $H_L H_L, x_0$, what is this ΔD point? This is the point, which is the difference of enthalpy's or total energy of any two streams, leaving that plate so vapor and the liquid, which means if you want to draw L_n, G_{n+1} you will have a straight line, where this will be L_n , you will have x_n . We have this $H_{G_{n+1}}$ and this will corresponds to y_{n+1} . Notice the difference between the two will give you ΔD , which is nothing but the difference enthalpy or the energy of leaving streams, which is $H_D + Q_c$ by D that is your Q' .

This coordinate is here, what this is your $H_D + Q_c$ by D . It is very important that we understand that, this is consistent with what we have written here because of this mixing rule. This vapor which arrives at n th plate and the liquid which leaves this n th plate, the difference between the two is same as, what happens to this hypothetical fluid with the molar flow rate D , but the energy with Q' difference is same, that means you can draw all lines here, passing through this ΔD points. This would be L_1 , this would be H_{G_2} , this will be L_1 , this would be G_2 , this would be L_2 then this would be G_3 , we are making this energy balance for, L_n and G_{n+1} .

Let us come back to the first tray of the distillation column, one the liquid which brought from the reflux as mole fraction x_0 and H_{x_0} and the vapor, which leaves is y_1 and y_1 is same as x_0 , because we were using total condensers.

So if you start from here, then this is y_1 , we locate this point as this just underneath this, we have this y_1 and this is y_2 plate two here and the liquid which leaves, this mole fraction is x_1 . For the top plate y_1 and x_1 , they are in the equilibrium or these two streams are in equilibrium, which means if this is y_1 , we cannot draw a tie line, which will intersect here to give you x_1 . Now take x_1 and connect this to ΔD , x_1 to y_2 that means, this will be one of G_2 . So, let us go back to this, the way we have written L_n , G_{n+1} , we can write L_1 , G_2 . We can write L_2 , G_3 etcetera, to connect in this all points here.

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Last time, we will redraw this H-x-y diagram for, total condenser. So we have this H-x-y diagram, this is H_V and this is H_L . And we are talking of total condenser, so we have Q_C , the vapor coming from the top plate as mole fraction is y_1 , and we have H_V etcetera. And then, we have the separator, then we have withdrawing this product D , we have x_D and we have H_D , and this reflux L_0 , x_0 , H_{L0} goes back to this top plate which is say one here, so this vapor is same as this and the liquid which arrives to the top plate as same as, this liquid which comes out from this total condenser.

So, since it is a total condenser, we have x_0 , x_D and y_1 , x_A . So, x_0 equal x_D equal y_1 , so let us mark, different enthalpy and x y coordinates here. So we start with we have this, x_0 same as x_D same as y_1 , so this point would be $H G 1$, so this $H V$ is nothing but $H G 1$, and we have the difference point ΔD , so this ΔD is nothing but the ratios of L over this D . So all we are saying that, L_0 over D it is same as the reflux ratio and same as Q dash minus $H G$ over $H G$ for the first plate $H G$ minus $H D$. So, this $H G H G 1$ here, and then this ΔD , it is a difference point with the enthalpy, which we have this Q prime here. So we can mark that, $H L_0$ if it is saturated as here $H L_0$. Now let us look at the top plate, this y_1 and this x_1 . The vapor leaving and the liquid leaving, they are in equilibriums.

So, once we have this y_1 , we have the first tie line as x_1 or corresponding to this L_1 . So, we know the difference point, we connect this as an operating line, so we get here y_2 . y_2 will have another operating line, intersecting here which is now x_2 , so again we connect this x_2 to this $H W T$, so all we are saying that, once we know this difference point ΔD , then we can connect x_1 , x_2 etcetera with this difference point here to obtain, the other coordinates on this vapor phase here. So, this is about the total condenser, when x_0 , x_D and y_1 , they are the same here and the enthalpy $H L_0$ is same as $H D$ and they differ from $H V$, because of this Q_c . So this ΔD , which we have the difference point has this enthalpy of what energy of Q prime, which is Q_c condenser load plus $H D$ over D .

The important point here to note is; the way we are drawing this stage one, stage two which are the tie lines, the vapor leaving the first plate and the liquid leaving the first plate, they are in equilibrium, so we have this tie line here. The second plate, the vapor leaving the second plate and the liquid leaving the second plate, they are in equilibrium, so this is your second tie line and the one which we join from here x_1 and x_2 to this ΔD point, that gives you the operating curve here which means that gives you, the concentrations between the liquid which the vapor which arrives here and the liquid leaves here.

So, this would be a connection between x_2 and y_1 , so notice this nomenclatures we have this y_1 , we have x_1 , we have y_2 , and we have x_2 . So x_1 to y_2 , we have operating line x_2 to y_3 , we have these operating lines. So this is about, total condenser

and similarly, we can have; we can mark the H x y point on the partial condenser, which we will do in the next class.