Mass Transfer II

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Lecture No. # 17

In the previous lecture, we discussed distillation with total condenser. So, today's lecture we continue our discussion on distillation with partial condenser. So, before we make this H X Y diagram, and put the coordinates of enthalpy's of different streams, it is important that we understand the difference between the total condenser, and partial condenser.

In case of total condenser we had this vapor phase compositions coming from the top plate Y 1, and when it condenses completely then we have a split part of the liquid or condensed mind goes back to the distillation column as a reflux. So, the composition of all 3 streams; Y 1, X L 0 which goes to the distillation column and the top product is the same.

This is the difference between the enthalpy. So, the enthalpy of the vapor which reaches the condenser, and the enthalpy of the steams which leave the condenser and the reflux they differ by latent heater of vaporizations. So, in case of partial condenser what we have that, we condense only part of the vapor which reaches the condenser which means we have the top product in the vapor phase, and the condenser goes to the distillate or to the distillation column as a reflux.

Here we have to be careful that the all 3 compositions Y 1, Y d, the top product and X L 0 which is the mole fractions of the reflux going to the distillation column all 3 of the them are different. And here the partial condenser works as a theoretical plate, because the vapor which leaves as product, and the liquid condenser which goes back to the distillation column as a reflux are in equilibrium. So, with that over view in the mind let us try to plot this H X Y diagram and mark our different compositions here.

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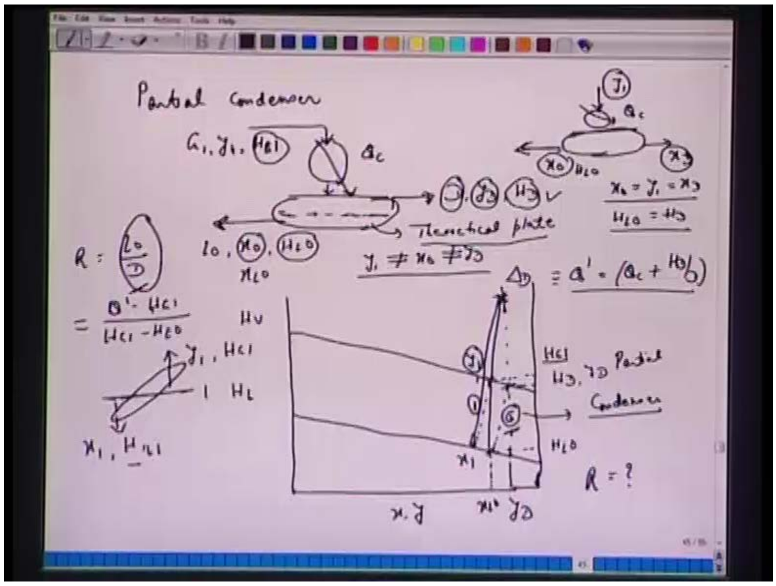

So, we are continuing our discussion on distillation with partial condenser. Here we have this condenser, Q c is a load here we have the vapor from the top plate. We can say G 1 molar flow rate y 1 is a mole fraction H G 1 is enthalpy. Then we showed the schematically this separator, so we had the separator now the top product which is been drawn from here is the vapor, so we have D molar flow rate and we have this y d, enthalpy is H D, and this condensate the liquid it goes back to the distillation column as a reflux. And we have L 0 X 0 and H L 0 reflux ratio is definition is the same, this is L 0 over D.

So, let see the difference what we have here, we have X 0 and y d, and this is your partial condenser which means these two mole fraction they will be on the tie line or on the equilibrium, because the vapor living here, and the liquid here they are in equilibrium. Therefore, this partial condenser is supposed to be a theoretical plate or equilibrium plate, and this composition y 1 is you can see y 1 is different from X 0, and it is different from y D. So, this is the difference between what we had in earlier when we had this total condenser.

So, when we had the total condenser and we had this Q c then y 1 x D the liquid, and here we have this x 0 the liquid phase or the reflux mole fraction all X 0 same as x D same as y 1. So, X 0 same as y 1 same as x D, so that is the difference here none of the 3 compositions are same here; in fact here we had the enthalpy H L 0 same as H D. When notice make a difference here enthalpy H D is different from H L 0 by this latent heater vaporizations.

Similarly this H D is different from H g 1 here, because there is a heat loss here Q c. So, now we can plot H X Y diagram for rectifying section with partial condenser, so we have x y here we have say this H V saturated vapor enthalpy we have this H L. So, let us start with y D, so we have this line at the mole fraction y D. Now once we have this y D lets mark H d and X 0 with H L 0, so this 2 first we have this tie line this enthalpy here it is given as H D saturated vapor enthalpy H D, and what here we have is X 0 or X L 0. So, X 0 is same as X L 0 and this enthalpy here is H L 0. We can also mark this Del D so, that was our differential point here equivalent to this Q prime, which equals Q C plus H D over D. So, this what we had this hypothetical steam which leaves are this molar flow rate of D, but it has the enthalpy of Q C plus S D by D.

So, this different point is fixed here, and first thing was note that here now we have to find this reflux ratio which is defined as L 0 by D. Let us start with what we have here is in the vapor phase compositions given at y D H D points, and this a tie line at x L 0 and we have H L 0. Now, we can connect this differencing point with X 0, so notice here now this is what we have here the first point will be now given as H G 1. So, this would be the enthalpy of the vapor which arrives to this condenser, and first tie line here must make a note that this is a theoretical plate.

Therefore, we will call it C. So, notice the difference between the total condenser, and the partial condenser the first stage which we have marked on this H X Y diagram represents condenser. It is acting as a theoretical plate it is a partial condenser, in total condenser we did not have this situations. Now starting from here now again this vapor phase will be in equilibrium with and the tie line here. So, that would be your first stage so, what we have done here we start from again y D we draw this tie line X L 0 which we have connected to the del D here, and then we have this second tie line which reaches here this is now X 1. So, we have X 1, and here we have this corresponding to this we have this Y 1. In fact this would this H D this should corresponds to we have y D here and then we have this mole fractions with this Y 1.

Now, let us go back to one distillation plate here tray here in which the first vapor the vapor form that plate number one leaves with this moles fraction y 1, and we have this liquid which leaves the top plate with mole fraction X 1, and this 2 steams are equilibrium so, we have H G 1 and here we have H 1 or H L 1.

Now, the same thing we have here the first tie line which we have drawn represents partial condenser, and the second tie line which we have drawn is a stage one. So, again we can connect with this differential line, and we can continue with our constructions here. The more important here is understanding the difference between the total condenser and the partial condenser through this. Now, look at the reflux ratios R reflux ratio definition is same as here L 0 by D which is we can also defined if you recall L 0 by D as a Q prime minus H G 1 over H G 1 minus H L 0.

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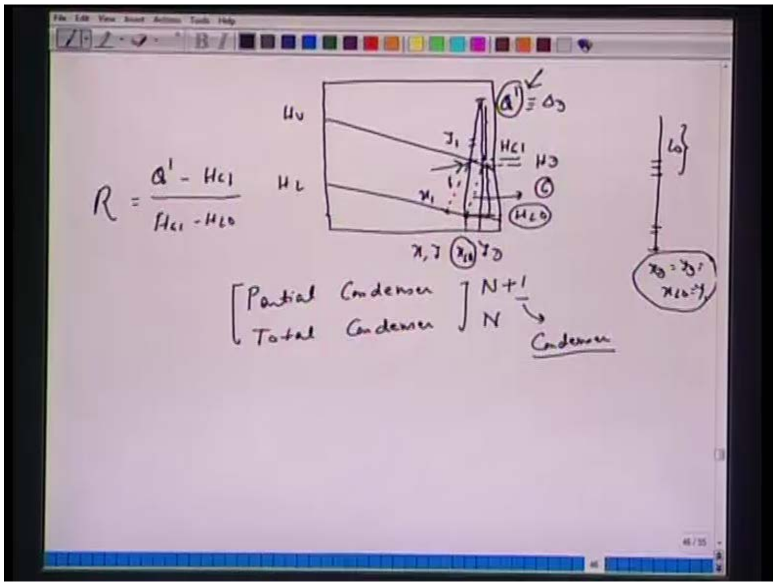

$$R = \frac{Q' - H_{G1}}{H_{G1} - H_{L0}}$$

Partial Condenser] N+1

Total Condenser] N

Condenser

To mark the same point let us start with the phase enthalpy curve here H X Y diagram we have this H V or H G and we have this H L. So, this is your del D or Q prime and we have this y D. The first line tie line equilibrium line which we have drawn this is C condenser this is X 0, and here we have this H D and this is H L 0 corresponding to this X L 0. As this a whole mole fraction of the liquid going back to the distillation column, and when you connect with this now we have the first operating curve here the corresponding to this X L 0 now we get Y 1. This Y 1 will be in equilibrium with X 1 mole fractions liquid so we have the first tray starting from here. Now with this one we should mark this as H G 1. So, H G 1 we have Q prime and we have this H L 0 so, this reflux ratio must be obtain from the segment here and here. So, notice the difference in the part total condenser, we use to have L 0 and d write from X D equal to Y D equal X L 0 equal to y1.

The construction for partial condenser and total condenser is different. The first line is this condenser, partial condenser, theoretical stage. Second tie line is actual plate number one and then on then on ward we have number two number three etcetera and the reflux ratio which we are obtaining it is a projection from here the first this operating line which we have drawn from here take the projection that will be H G 1 minus H L 0. So, reflux ratio R is Q dash, which is here minus H G 1 enthalpy of the vapor live in the first stage which is here not here do not make a mistake very often you make a mistake here, because in case of total condenser, we use to take the segment the first segment or operating line which we use to obtain here the first operating line is starts from stage one here.

Now, Q prime minus H G 1 over H G 1 minus H L 0 which would be this H L 0 here. So, with that we can construct this H L X Y diagram to have the two scenarios: one was Partial Condenser and the second was Total Condenser. So, the difference here between that if number of plates here we have N, then case of partial condenser we have one more plates representing this condenser because this acts as a theoretical plate 2 living steams or a equilibrium.

This completes our discussion for the first part of the distillation column top part it we call it rectifying sections. So, the feed enters at a certain plate, and all the plates all the segments section above the feed plates all we have this rectifying sections, and under need we have this a stripping sections.

So, whether we have rectifying section or we have a stripping sections at any section we have the vapor living the tray going up, and the liquid trickling down here, then we made the enthalpy balance we took is one envelop which intersects at any arbitrary location all the plate N. And then we said that the difference between the liquid and the vapor it is constant given by this D. Similarly, that enthalpy difference between the liquid and this vapor is given by this Q primes, so we have incorporation of this condenser load to the enthalpy of this living product; similarly, for this species balance also made similar and all these 3 streams which you have liquid vapor and this top product whether it is a enthalpy or whether it is a species the it falls on one a straight line, so we are applying mixing rule. Therefore, the similar approach we should be able to do it for a rectifying sections, so in the rectifying sections we have the similar story the liquid will trickle down now its comes to a boiler.

Where part of this liquid is vaporized and sent back to the distillation column. So, there we have this liquid reflux and now we have here is vapor reflux and the product which comes out is a liquid. So, notice the difference that here all the time we have this boiler which is also going to act as a theoretical plate because we have the liquid as a product and the part of this liquid which has trickle down from the bottom plane N P has been vaporized.

We have similar situation vapor and liquid living we assume it is ideal if 100 percent efficiency than equilibrium and the mole fractions are the coordinate will lie on this equilibrium or the tie lines. So, for the rectifying section all the time we have this situations what we had in case of partial condenser for rectifying sections. So, again here also, we will make on enthalpy balance we will make species balance, we will make a total balance molar flow rates to marked our points for all in this stripping sections.

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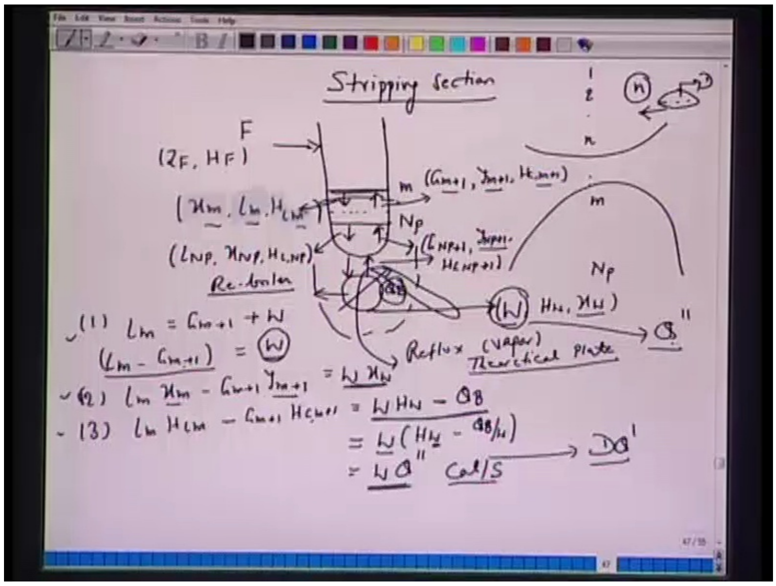
Stripping section

(1) $L_m = G_{m+1} + W$

$(L_m - G_{m+1}) = W$

(2) $L_m x_m - G_{m+1} y_{m+1} = W x_W$

(3) $L_m H_{Lm} - G_{m+1} H_{G,m+1} = W H_W - Q_B$

$= W(H_W - Q_B/W)$

$= W Q''$ Cal/S $\longrightarrow DQ'$

So, let us start this a stripping sections. So, this is bottom part of this distillation column under need this feed plate so, we have this column like this is a last plate so, this plate is N P number of plate is N P here, so and feeds a lets enter here F, so we have Z f mole fraction we have H F any arbitrary plate here the distillation column we are representing with m so, the nomenclature which we use for rectifying section was n here we have m for our convenience M, we have counting still we start from the top 1 2 n and continue with this m and the last plate is N P.

So, we have this envelop here and we have this envelop here, so we are looking at this bottom part here. Now we choose m here the vapor which arrives has the aspect G m plus 1, so we doing the counting form, so there is another plate here if you call it there is a last plate which we have drawn here N P. G m plus 1 y m plus 1 and we have H g m plus 1. The liquid which leaves this m mth plate and trickles down to the bottom is has aspect X m L m H L m. So, we are following the same nomenclatures that the all this suffix or subscript they represents the trays from which the vapor are the liquid originates. If the last N P then we have this G N P plus 1 y N P plus 1 and here we have H G N P plus 1 the liquid which trickles from the bottom plate has L N P X N P, and we have H L N P. This is what we have done now will can take this hypothetical this X N here like this liquids which drops and from the plate trickles goes to now a boiler, so this boiler we gives energy Q B heat calorie per second part of this liquid is removed as this bottom product.

So, W H W and we have this X W and part of this liquid is vaporized to send back as a reflux. So, notice this reflux is vapor unlike in the top section rectifying section we had the reflux as the liquid. So, this is boiler and as for our discussion this vapor can be a this vapor which leaves the boiler as the same aspects as this vapor which arrives the bottom plate N P. So, is the same the only thing this vapor is in equilibrium with this liquid. X W and y N P plus one they will follow on the same equilibrium curve that is why this last plate is also a theoretical plate. Therefore, by default re boiler in a distillation column we have this theoretical plate one plate extra like we had in case of rectifying section where we had the top, where we have condenser if you it acts as a partial condenser then we had this theoretical plate one plate extra.

Now we have taken this envelop this under need this m mth plate and it intersects here, so we can make the 3 balance total molar flow rate balance which we can write as L m equals G m plus 1 plus W, so L m is this is stream equal to G m plus 1 equal to W, and we can rearrange to write L m minus G m plus 1 equal to W. Now again try to make an analogy what does it mean L m minus G m plus 1 L 1 minus G 2 L 2 minus G 3 the difference of the molar flow rate of the liquid living this tray, and the vapor reaching that plate is a constant same as W you can compare this with L n G n minus 1, and the top product which was D here.

So, this is going to give us a difference point for this bottom column, we will mark that number two will be your species balance L m X m minus G m plus 1 y m plus 1 equals W and X W. So, it is a species balance for the mole volatile components a or b whatever here third is L m H L m minus G m plus 1 H G m plus 1 equals W H W, but now we have minus Q B or you can bring this Q B on the left hand side to convince yourself that is in the re boiler right, this is your boiler or re-boiler. Therefore, we are giving this energy of Q B, so this is our energy balance here.

So, we have total balance we have a species balance and we have this energy balance this W and if we time we are writing this right hand side as a constant, so that is what the difference point this going to or give us W X W and W H W minus Q B which can be rearrange to give W H W minus Q B over W, and similar to this we can call it W Q prime. Therefore u can compare the previous one we had D, and we had this Q prime which included minus of this Q C or in here we had this plus of Q C, so again this is hypothetical stream leaves this envelop with the molar flow rated W, but it contains a energy of Q dash to incorporate the heat energy or boiler which you are giving to this Q B. So, this unit is calorie per second calorie per mole, and then you have enthalpy calorie per second for W and S W, you have calorie per mole to make it calorie, so this is the rate of the steam hypothetically steam which molar flow rate w leaves with this, so much of energy.

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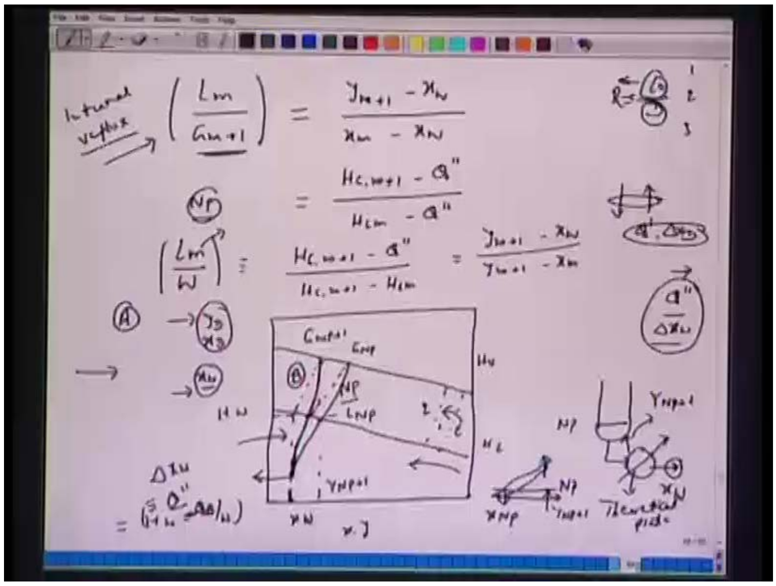

So, with this 3 equations we can again simplify or we can rearrange to write L m over G m plus 1, so this is the same similar expression we obtain for the top column this would be your internal reflux, if you call it we had external reflux or just like internal reflux L m vapor liquid molar flow rate which trickles down to G m plus 1 at any locations which moves up. So, the ratio of this internal reflux similar to L m over G m plus 1 we had earlier this will be equal to m y m plus 1 minus x w over x m minus x w, and similarly from your energy balance or your enthalpy balance we can write H G m plus 1 minus Q double prime over H L m minus Q double prime.

As we can also eliminate G m plus 1 from the total molar flow rates to make it L m by W, so this is equivalent your R equal to L 0 over D we had the counting from the top 1 2 3, so we had this L 0 internal reflux that you external reflux the liquid which goes inside the column to product which we remove from the top. So, similarly, we have here we have L m over this W and L m over w one can write like H G m plus 1 minus Q prime Q double prime over H G m plus 1 minus H L m, it is a general H L m this can be written as y m plus 1 minus x w over y m plus 1 minus x m. So, in this m if we put N P plus 1 or you put N P, the top bottom plate you will get L N P over W or L 1 over W or L 2 over W etcetera. So, all we have done again we have able to identify our difference points the difference between the liquid, and the vapor this difference is constant with this what leaves at the bottom of the column. So, similar to x D now we have this W X W the above with Q prime earlier we had Q prime with w x D.

Now, we can draw H X Y diagram with this so, we have this X Y we have this H L saturated liquid enthalpy and we have this H V and H L, now we are starting from here the mole fractions of mole volatile component is small here right, we have a distillations feed enters here top product rich N A. So, we have y D or x D very large it is 90 percent 95 percent and the bottom product its lean in mole volatile components, so we have this X W very small, so if a is mole volatile components, then b this is steam bottom product will be rich in b, and lean in X W.

So, we are here and let us mark this point. So, we take this as X W, and here we have you can lets draw next to this we have this distillation column, we have this boiler, this is X W and the vapor which goes into this it is an equilibrium with this X W, you call it Y N P plus 1. So, if this liquid which leaves a saturated here we have this H W and then this liquid is an equilibrium with this vapor, so we can draw the first tie line this will corresponds to G N P plus 1 or correspond to this. We will have Y N P plus 1 and on this X W; the more important is now your difference point del X W or you have Q double prime so, we have this Q double prime equivalent to H W minus Q B over W. This is the re boiler load equivalent to this Q C which we had for the top column, so we can mark this point here once we have mark this point here, now it is easy to draw first line which you drawn again we can put B, if you recall B is equivalent you see there; the first this re boiler acts as a theoretical plate.

This is theoretical plate and the first plate of the bottom column or N P starts from the normal, so the first tie is always B tie line, and one we have drawn from here to the difference point, if you draw like this you can point this will from this. Now, you can take another tie line that line will corresponds to now N P. notice the difference we started from this way we had the first tie line for partial condenser that was C, and then onward whatever we had we had 1 2 etcetera we reach N P here, and once we reach N P here then again we can keep on reconstruction this point, now N P is corresponds here will be now correspond to L N P.

Again if you take the bottom plate which is N P the vapor which leaves which reaches here is y N P plus 1, and the liquid which reaches leaves here is x N P, and they come from the operating line, vapor which reaches here leaves this plate that would be in equilibrium with this, so we have the operating line and we have this tie line, this what we doing here tie line connect this to different point X W, then connect to this N P, we get this L N P. So, again we can continue with this G N P plus 1 we have G N P G N P minus one from this side as well as you have done it from this side here, so let us quickly summarize what we have done in today's lecture. What is today's lecture is started from top column did the discussion for partial condenser, so partial condenser is a special case where we have this vapor top product is of vapor, and it is an equilibrium with the liquid or the reflux which goes back to distillation column in case of bottom column all this stripping sections right.

We have this boiler, so boiler always acts as a theoretical plate at least we assume it is a ideal hundred percent efficiencies, so in this case all the time the liquid which we have been drawing bottom B in the vapor this liquid phase is always in equilibrium with the reflux vapor which goes to the distillation column. So, the bottom this boiler is always a theoretical plate, so with that mine again if you choose any plate m and in this stripping sections and you look at the liquid which tickles down and the vapor which goes up the difference between the two molar or the species a or the enthalpy is always conserved, and same as your the bottom product which is living D with Q double prime energy with that Q double prime incorporate or includes boiler load. Once we mark this difference points, then we can draw all the operating lines write adding sections N P liquid going down vapor goes up what is the connection between the vapor phase compositions liquid phase compositions enthalpy of the vapor enthalpy of the liquid there will come from the operating line tie line will give you the vapor leaving that plate with the liquid living that same plate.

So, tie line will come like this so, one can do the constructions for both the rectifying section and the stripping sections starting from here, and from there, and what is the missing now is the species balance or the energy balance or the total balance for the entire distillation column. And remember we said that just one mixing rule, we are applying all the time for the top column, and the bottom column either for the species or for the energy to show that the difference remain the same; that means the two points a and b will give raise to see or from see if its extract A or B, it will give you the other components and all these 3 lines will lying on a straight line.

So, that is why we have X W, here and we have X B the origin, and from X B you can draw all the operating curves from X W X D, also you can draw all the operating lines etcetera, so what happens? If we now you make a balance with incoming is a feed f and we have the top product D and the bottom product B or we have X F we have X D or y D and we have X W here or we have H F energy H F, which we are giving which feed carries with a, and we are living is Q prime that includes your condenser load and we have Q double prime that includes your boiler load.

So, if you now you make the energy balance or a species balance, you should able to appreciate that again this f coordinates for f; whether species or the energy, and those for your top product and the bottom product will lie on a straight line. So, if you connect X W with X D with X W, we should appreciate we should be we should we should note that F feed has to lie on this straight line, so with that over view you can we can complete you can make this energy balance or enthalpy balance for the entire column.

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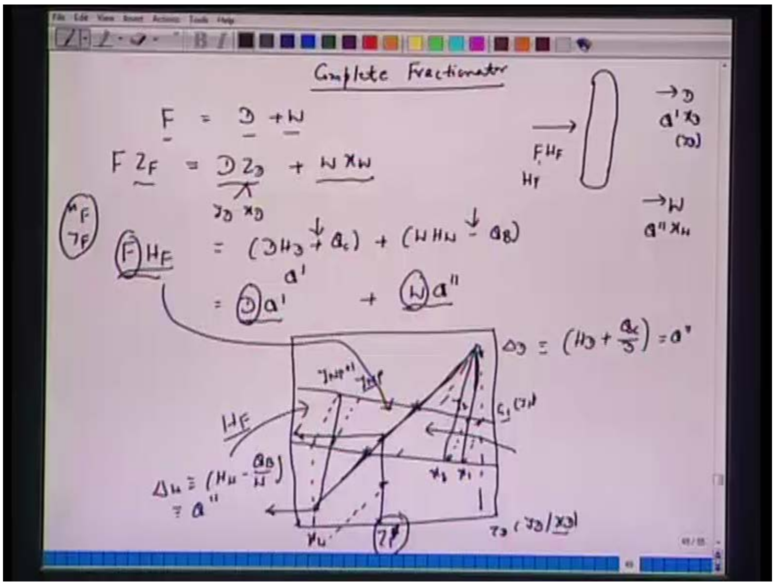
Complete Fractionator

$$F = D + W$$

$$F z_F = D z_D + W x_W$$

$$F H_F = (D H_D + Q_C) + (W H_W - Q_B)$$

$$= D Q' + W Q''$$

$$\Delta_D = \left(H_D + \frac{Q_C}{D}\right) = Q'$$

$$\Delta_W = \left(H_W - \frac{Q_B}{W}\right) = Q''$$

Now, let us have this complete fractionators, so what we have is F equals D plus w, so this what we are saying that now we are making n overall balance, F enters here, and we have this D and here we have W. We have Q dash and Q double prime this Q dash includes Q C, and Q double dash includes your Q B expect one is negative one is positive one is boiler one is a condenser and here we have F and H F, we have X W, we have X D or we can have y D also depend upon whether it is a partial condenser the product is vapor or we have the total condenser, and here we have this H F.

We writing F equals D plus W F Z F again, we use this nomenclature for Z F to say that whether this could be total liquid X F or this could be y F or this could be combination of liquid plus vapor mixed, so F Z F equals D Z D again Z D has either y D or X D plus W X W we can also write F H F, so total energy in is total energy out D H D plus Q C which we call it Q dash plus W H W minus Q B. Therefore, we can notice here plus Q C and minus Q B this energy is goes into the system, and this will also be we can write it as D, so Q dash and you can plus W as Q double dash, so F H F D Q dash W Q dash F Z F D Z D or D X D W X W F equals D plus W. Now, we can construct our enthalpy for the entire each H X Y diagram for this entire distillation column; of course, we have done for top column top part rectifying sections and the bottom stripping section separately or we have to do is to just to connect.

So, first if we start from here suppose this is your Z D here, which could be y D or if could be X D, now right let us go with this total condenser X D here, we have this H F saturated vapor. And we have this saturated enthalpy curve here. We can mark this as del d this del D is H D plus Q C over D or Q double dash; and similarly, here we have X W and here we will have del W point which is equivalent which represents H W minus Q B over w and we call it Q double prime and then we started drawing this curve, so first we have this operating curve y 1 or we call it G 1; similarly, we connected with this we connected with this, so we have X 1 then we have this Y 2 and again draw the tie line again this connect with this you can keep on margin; similarly, here we can also go with the bottom this is boiler, so tie line this will be y N P plus one connect with this difference point del W then we have another tie line like this which would be y N P, so all G N P plus 1 G N P or we can go with G 1, G 2, Y 1, Y 2, X 1, X 2, etcetera.

Now, if you connect this X W and X W this what we trying to get here write F feed coordinates, and D coordinates and w coordinates they have to lie on the straight line by mixing rule; that means if the feed compositions let say Z F right, this has to lie on this straight line this would be the enthalpy of the feed H F if you drawn like this. Now, all we have done we have started with the left which is your stripping section rectifying section or we can start from here, which is your stripping section, and we if we want to mark this feed, then feed if composition of feed enthalpy of the feed this has to we can draw a straight line between the two realizing that we applying mixing rule here, it has to be straight line we can get the feed compositions or if the feed compositions. And we can know the you can mark this enthalpy line feed can be saturated liquid it can be saturated vapor or it could be mixed of this or feed can be cold right, it is all possibility there. So, in the feed is here; that means this line has to be drawn from here, and this point what we have Q dash prime it has to move downward idea is that all this 3 F D W they have to lie on the same straight line joining between this and this.

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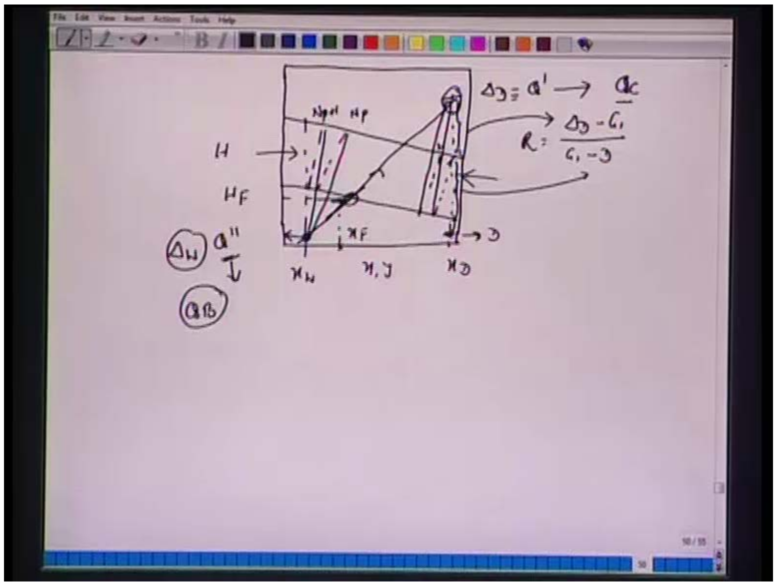

Let us do it again here, so we have this H X Y diagram for the complete distillation column, so let us do it one more time may be slightly different way, so we have X Y we have H L, we have H V here, suppose we know this del D points, and how to we know of course. So, we can take on the reflux ratios; that mean this ratio by this ratio is your R del D minus G 1 over G 1 minus or G 1 del D this segment and we have this segment G 1 in d here, so let us say this is your D here.

So, this is X T may be this top product this cold, so it does not lie or not necessary it as lie on here, so its X T enthalpy is given here h here we know the reflux ratios so, we can take the 2 segments 1 segment here 1 segment here we can mark this Del D points now let us say that the feed composition is known to us.

So, we take the and feed is saturated liquid so, we mark this X F and we mark this H F. We can always go from here, we can take this; first tie line we can connect with this second tie line, we can connect with this, and we can do extra Y 1, Y 2 ,Y 3 etcetera. Suppose we now we know H F, and X F all it means it connect this point here we connect passing through this, then this has to lie and wherever insects with X W, this has to be your Del W points. So, this what we trying to say here in the previous slide here, this is Q prime this is Q double prime all this 3 points feed, and X M they have to lie on this straight line.

So, if this point the feed status enthalpy of this we connect this bring to this X W, this point will be Q double prime may be from here we can calculate boiler load or if the boiler load, we can mark this point. And we know the feed we can draw like this, and wherever intersect with the vertical line going through this X T, we can calculate Q dash from this. We can get condenser load one can also start from here connect with this difference point, another tie line like this and we can N P plus 1 to N P.

So, we have first 1, 2, 3, etcetera to cover from this way or from this way. So, this is the your complete fractionations for rectifying section for stripping sections you must to understand the degree of freedom right, the problem can be rephrase in so many ways in some cases condenser load will be given some cases your boiler load is given in some cases may be the feed is given you are, suppose to find the condenser load. So, one has to make this property of this enthalpy balance or a species balance or the mixing tool to realize that to mark this difference point of del D and del W and the F.

The two you can find the third if the reflux ratios, we can find Del D and if the feed we can connect this to get del W and we can do the calculations.

So, everywhere at any plate many segment whether it is a top section or the bottom section one has to make this enthalpy balance species balance, one should make use of this property of this mixing rule 200 and 5 each and every points. And then depending upon the type of problems one can address different condenser load, what is the condenser load given the reflux ratio, what is the boiler load etcetera or if the condenser load boiler load we know the feed compositions, and the distillate composition or the bottom product composition what is the reflux ratios. We draw this lines take the ratios of those two segments to get the reflux ratios. What we do now very shortly is the reflux ratio itself reflux ratio as we said earlier it defined as L 0 over D.

Now, what happens? If we increase the reflux ratios, so we have your condenser part of this condenser or let us say we have total condenser, so entire vapor is condensed or you have the liquid product how much fraction of this you should send back to the distillation column and how much product you should be drawing it. So, what happens if we change the reflux ratios, and is then a limit if you keep on increasing the reflux ratios or if you keep on decreasing the reflux ratio is there any is there two limits here that is why we are going to address. Now, look at this your if we increase the reflux ratio that means the liquid going down to the going to the column is very large. So, if you have larger liquid going to the column condenser load is lot it increases. Now the liquid goes down to the distillation column is large here that means it will put a load on this boiler as well. So, we will like to locate how does the del D and del W it moves with this increasing and decreasing reflux ratios.

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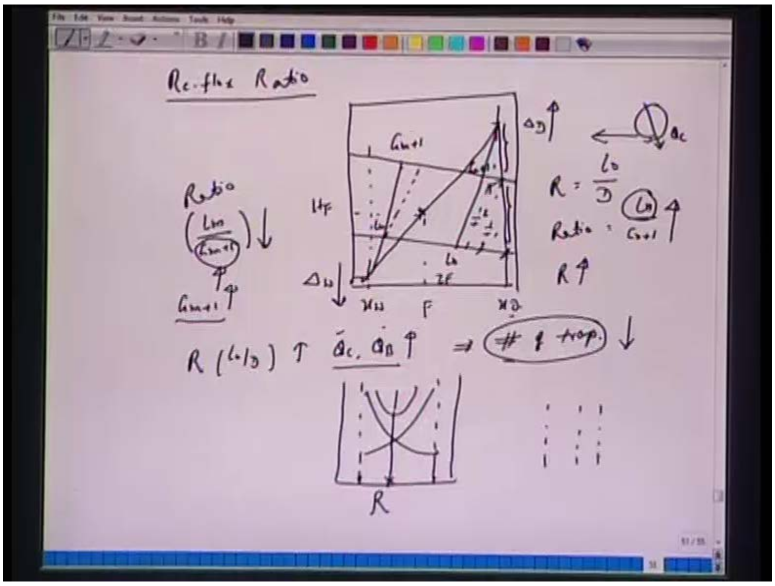

So, let us address this here that what we have is a Reflux Ratio. So, let us redraw this curve again we have this H G and we have this H L. Now we have this del D this point here, and we said that let say the feed is or the top product is saturated, so this will be the ratios R as L 0 by D and what happens to this ratios as L N by G N plus1.

Similarly here we have also this ratios of L M over G M plus 1. So, we have this Del D if we draw like this, we have this X W we have this del W, and then we can draw say arbitrarily line here which is say G M plus 1, we have L M we can draw arbitrarily line from here. Let say we have G N plus 1, and we have this L N this is X D here.

Now, if the reflux ratio increases, you can notice that this point will move upward. So, thus a locus if del D move upward f is fixed right, say let say F H F and Z F is fixed here.

Now, if this points moves upward, you can see the del w point has to move downward because it is a 3 F D F D, and w they have to lie on this straight line; so, all it means if this ratio increases this ratio will decrease. So, the load L N increases on the condenser we are taking larger reflux here, so load on Q C or Q C increases here. Now, if this ratio increases this ratio is a decreasing, you can see that G M plus 1 increases. That means, the vapor load on the re boiler also increases right. So, all it means we can write here that if the reflux ratio R L 0 by D increases Q C as well as Q B will increase. So, load increases just mark follow this w keep the f fixed, and increase this Del D reflux ratios.

Therefore, in that case Del W will also will increase here all it means L N is increasing and G N plus 1 is decreasing increasing here in which case we have Q C and Q B increasing here. Now what happens to the number of trays the number of trays if you recall we had stages like this we connected with this second stage all the tie lines equilibrium line which we have drawn from this, see from the operating curves wherever intersects we have draw drawn those equilibrium curves. Now if this points moves up and this point goes down you can see the trend of this stages or it tie lines which you have drawn it becomes vertical and vertical all it means that you will number of trays you can show that you should plot it and convince you say that number of trays will decrease.

Otherwise also think of from the mass transfer point of view that if increase the reflux ratio the driving force between the gas with the vapor phase and the liquid phase increases and we have less number of trays. So, there is always a cost concentration if you plot reflux ratios, because of Q C and Q B the cost will increase, but however the number of trays fix cost for increase and there is a some kind of optimum here. We have of course, we have not defined here what is our maximum limit here, and what is the minimum limit here, but looking at this curve or the locus del D going up, and del w going down you can think that at a very extreme under very extreme conditions when there is del d very large or these tie lines will become vertical.

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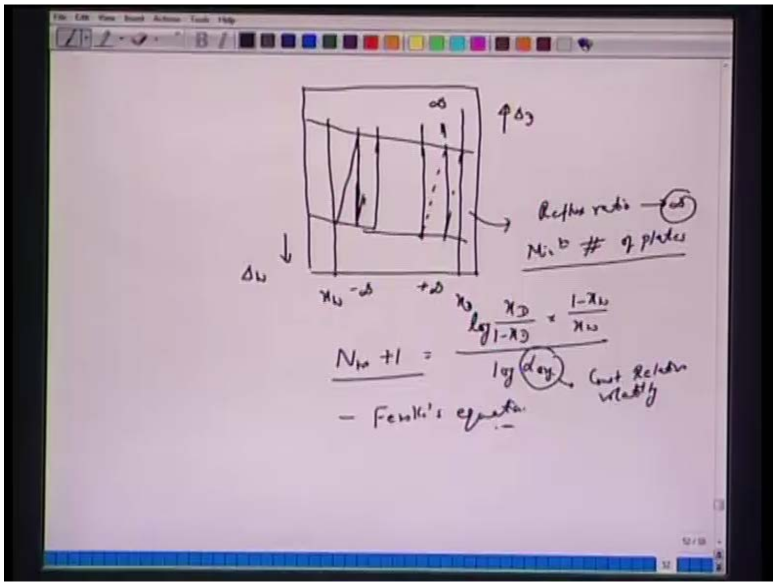

Reflux ratio → ∞

Min^m # of plates

$$N_m + 1 = \frac{\log \frac{x_D}{1-x_D} \times \frac{1-x_W}{x_W}}{\log \alpha_{avg}}$$

Const Relative volatility

– Fenske's equation

If you plot this for very large reflux ratios which will call it infinite reflux ratios, so we have this H G, we have this H L, and if we increase the reflux ratios; this point is fixed at X D, this point is fixed at X W this coordinate, and if we increase your del W del D and del W like this. Then all we have at every place we have this vertical, see operating line has to come from plus infinity; similarly, here we can have lines like this, then we have this and we have this vertical. All of this is coming from minus infinity to plus infinity. So, this gives us reflux ratio at reflux ratio tends to infinity, we have essentially minimum number of plates. An under these conditions when we have this operating line going vertically upward we can one can also calculate total number of plates analytically; in this case, I leave this as an exercise on can show that minimum number of plates at infinite reflux ratios equals 1 minus X W here over X W over log alpha average. If you take constant enthalpy, constant to relative volatility excuse me constant relative volatility; one can obtain this equation analytically for minimum number of plates at infinite reflux ratios; and this equation is called well known Fenske's equation. To calculate minimum number of plates at infinite reflux ratio, another extreme case would be when we have this minimum reflux ratios.

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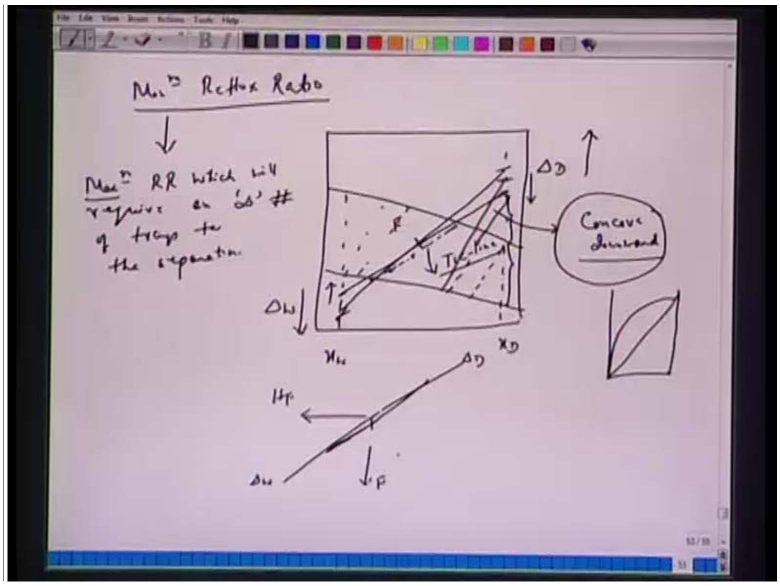

Min^m Reflux Ratio

Max^m RR which will require an '∞' # of trays for the separation.

When we have minimum reflux ratio ratios; now let us redraw this H X Y diagram again and follow the locus of this del D and del W points. So, we have this X T and here we have this X W. Now, we are connecting the 2 points del D and del W through this passing through this F. So, the first case was when we increase the reflux ratios this point goes up, now what happens? If you decrease these reflux ratios, now we have this line will go like this, and this del W point will move upward.

Now, in this case what happens? There is a possibility that the line which you are drawing here, the del D with this del w passing through this f it might coincide with this tie line. And if that happens then the driving force is 0, and you have infinite number of plates, and this very obtain it happens like this when the tie line corresponds to this operating line passing through this del D and del W passing through this F when your equilibrium curve is concave downward. When we are asked to calculate minimum reflux ratios we have to find that tie line, the operating line which as passes which is parallel which is coincides with this del W and del W line. So, this will gives us minimum reflux ratios, if we take this segment this by this will give us minimum reflux ratios.

So, we can write minimum reflux ratio is maximum reflux ratio which will require, and infinite number of trays for this separation. So, why this maximum reflux ratio here, because there is a possibility that some other tie line, if you draw tie lines from here or several tie lines like this in this x n or in this x n it is possible that this line which you are drawing here with w d through w d might coincide with this operating line. So, it is not necessarily that the tie line has to pass through this f, but as we said that when the equilibrium curve is concave downward passing through its 45 degree curve is like this, then most likely hood the operating line which passes through this F coincides with this tie line, which passes through this f in that case on this will give is minimum reflux ratios.

Otherwise there is a possibility that we have some other tie line which might gave max reflux ratio greater than passing through this. So, that really happens when we have situation like non ideality isentropic distillation etcetera. So far the time being this is for our calculations we are finding at tie line passing through this f, which is coinciding with del D, and del W line with feeds somewhere here. So, we will like to conclude today sections with this reflux ratios maximum and minimum reflux ratios, so we said that let us if we increase the reflux ratio then Q B load on boiler load on condenser increases, we have large amount of liquid large amount of vapor to make up for this. So, the pump requirement also increases what decreases is number of plates high reflux ratios, if you plot on X Y X diagram one can show, we will going details when we take up the next method McCabe Thiele method that the driving force between the equilibrium curve, and the operating line increases. Here also you should be able to appreciate by construction that the del d increases or del w increase in the opposite directions, then we required minimum number of plates.

So, by increasing the reflux ratios we have two opposing cost; one is the fix cost, one is the operating cost, and we talked about this optimum, and we have a limit at that limit is a infinite reflux ratios when we have minimum number of plates. And we talked out the second limit when we have R minimum, which gives infinite number of plates of course that is a very abstract or theoretical concept when we start decreasing the reflux ratios, there is a risk of operating lines coinciding with the tie line. Because a curve starts becoming less, and less line and it hits or it becomes it falls on this tie line or equilibrium curve that time driving force becomes 0, and will distillation will ultimately stop there.

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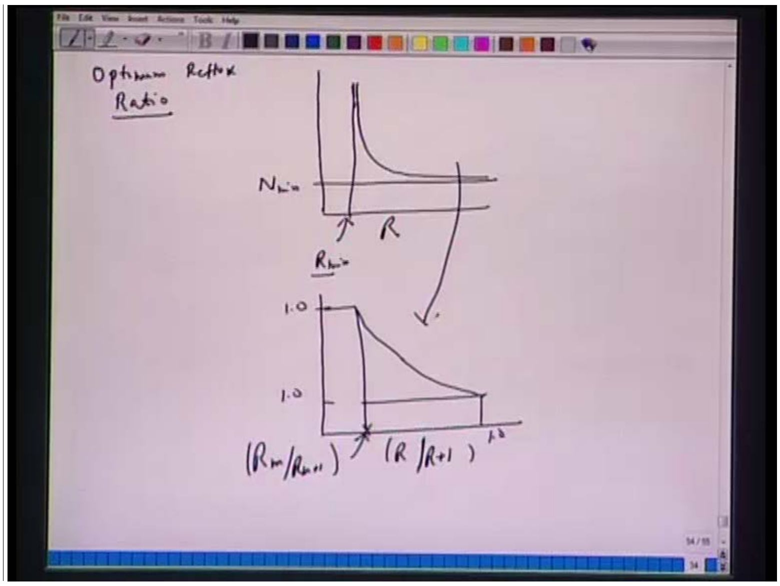

Where still with these 2 reflux ratios one can plot very nicely with. So, if you plot reflux ratios R to address this optimum reflux ratios, we can see that if increase the reflux ratios it goes to infinity very large we have minimum number of plates. So, that is one limit and there is a R minimum where we required infinite number of plates, so we have the shape like this and equivalent of this one can also plot R M over R M plus 1. So, similar curve we were trying to represent different ways one here, we have one here we have this one in this case we have this point here which is R M over R M plus 1. So, it is a minimum reflux ratios. So, we are plotting R over R M plus 1 excuse me. So, we have R over R plus 1 so, this corresponds to this point here R M by R M plus 1, and we can have actually bounded curve like this going there one for infinite ratios, so ultimately we have essentially the same curve we have plotted in a different ways. So, this ends our discursion for marking silent points silent coordinates for a H X Y system on h x y plot for top column reflux rectifying sections, and the bottom column stripping sections and the complete fractionators including d boiler and the condenser.

We know or to get the maximum reflux ratios, and or to we get this minimum reflux ratios. In one case when we had infinite reflux ratios, we had one analytical expressions which you can obtained you can refer to the text one can obtain analytically we call it Fenske’s equation. So, now in the next class we will try to locate the exact location of feed here feed plate before taking one example.