Mass Transfer Operations -I
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Lecture - 25
Absorption in plate column Method of McCabe & Thiele-graphical determination of ideal trays and Introduction to multicomponent absorption

Welcome to the 5th lecture of module 4 of mass transfer operation. In this module, we are discussing Absorption Mass Transfer. Before going to this lecture let us have brief recap on our previous lecture. In our previous lecture, we have discussed three important things.

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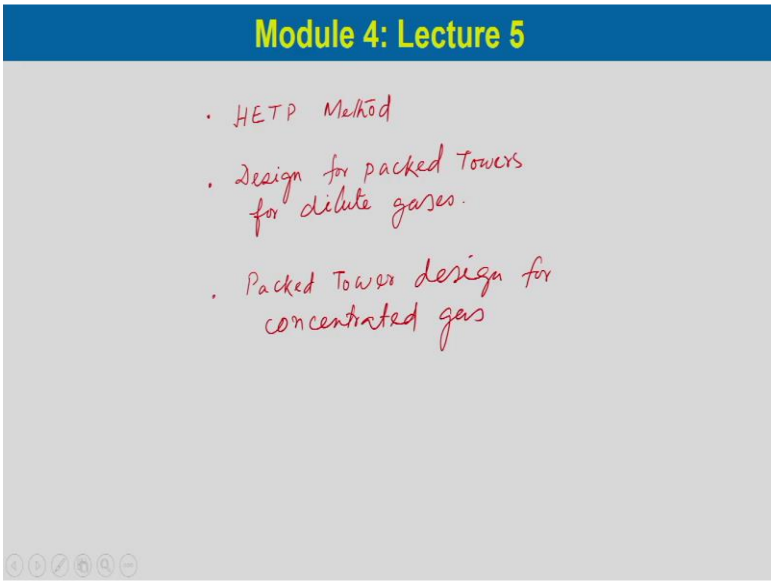

Module 4: Lecture 5

- HETP Method
- Design for packed Towers for dilute gases.
- Packed Tower design for concentrated gas

One is design based on HETP method - Height Equivalent to a Theoretical Plate HETP method. And second thing we have considered how to simplify the general procedure for designing a packed towers and how to simplify the packed tower design equation to calculate the height of packing require for the dilute gases.

So, design for packed towers for dilute gases. The third thing we have considered here the packed tower design for concentrated gases. In this lecture, we will mostly consider on the design of plate towers and both for the single component absorption and also for introduction to the multi-component system. Now, let us consider absorption in tray towers. As we have introduced during the discussion of our equipment for absorption and distillation process, there are two major towers one is packed towers and another is tray towers or tray absorber.

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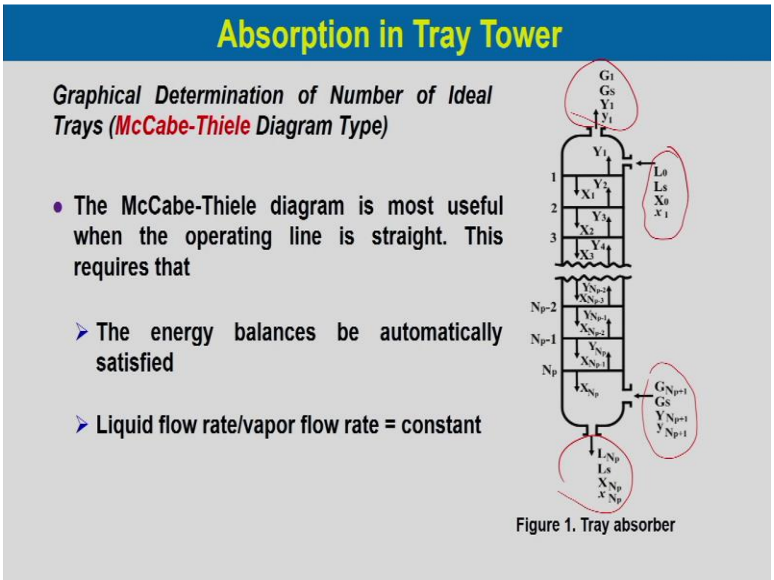

Absorption in Tray Tower

Graphical Determination of Number of Ideal Trays (McCabe-Thiele Diagram Type)

- The McCabe-Thiele diagram is most useful when the operating line is straight. This requires that
  - The energy balances be automatically satisfied
  - Liquid flow rate/vapor flow rate = constant

Figure 1. Tray absorber

So, in this case, in tray absorber to find out the number of ideal trays we can use there is a special kind of design procedure which is known as McCabe-Thiele diagram type. So, you can see over here in the packed towers the liquid which enter at the top having this composition and the gases which enter at the bottom and which is in this composition, and also the gas flow rate and liquid flow rate both gases of the inlet liquid and gas are mentioned over here. And we have a outlet liquid at the bottom and outlet gas at the top, both the flow rates and their compositions are mentioned. And trays are numbered from the top of the column 1, 2, 3 up to N p.

So, as you can see from this is counter current absorber. So, we will mostly consider counter current absorber design over here for the plate columns. The McCabe-Thiele diagram is most useful when the operating line is straight. If the operating lines are straight, this is easier to do the graphical calculation of number of ideal trays. So, for these we need to require some assumptions that is the energy balances be automatically satisfied and liquid flow rate by vapour flow rate remains constant. So, the ratio remains constant L by G.

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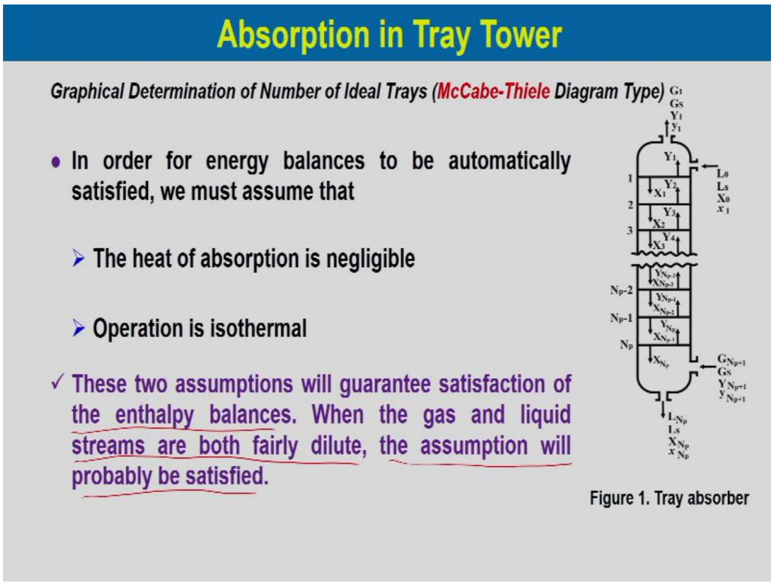

Absorption in Tray Tower

Graphical Determination of Number of Ideal Trays (McCabe-Thiele Diagram Type)

- In order for energy balances to be automatically satisfied, we must assume that
  - The heat of absorption is negligible
  - Operation is isothermal

✓ These two assumptions will guarantee satisfaction of the enthalpy balances. When the gas and liquid streams are both fairly dilute, the assumption will probably be satisfied.

Figure 1. Tray absorber

Now, in order for energy balance to be automatically satisfied, we must assume that the heat of absorption is negligible, so very negligible heat of absorption. There is a reactions between the solvent and the solute because of the solubility of a certain component based on the affinity of the solvent it generates huge amount of heat then we cannot use this type of method.

Only the cases where heat of absorption is negligible then only this energy balance would be automatically satisfied and operations should be isothermal in nature. These two assumptions will know guarantee satisfaction of the enthalpy balance equation when the gas and liquid streams are both fairly dilute the assumptions will probably be satisfied. So, basically when we have a dilute gas mixture and the solute transfer is negligible, so the change of heat due to the absorption is very less and we can consider isothermal operation of the column.

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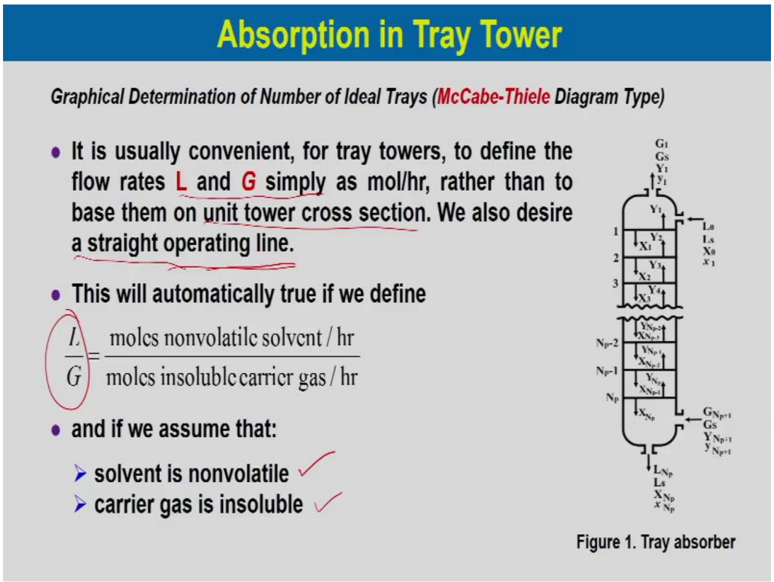

Absorption in Tray Tower

Graphical Determination of Number of Ideal Trays (McCabe-Thiele Diagram Type)

- It is usually convenient, for tray towers, to define the flow rates L and G simply as mol/hr, rather than to base them on unit tower cross section. We also desire a straight operating line.
- This will automatically true if we define

$$\frac{L}{G} = \frac{\text{moles nonvolatile solvent / hr}}{\text{moles insoluble carrier gas / hr}}$$

- and if we assume that:
  - solvent is nonvolatile ✓
  - carrier gas is insoluble ✓

Figure 1. Tray absorber

Now, it is usually convenient, for tray towers, to define the flow rates L and G simply as mole per hour, rather than based on the unit tower cross section. And we also desire a straight operating line. So, this is the things we need this will automatically true if we define L by G is equal to moles of nonvolatile solvent per hour divided by moles of insoluble carrier gas per hour.

So, this is L by G. And if we assume that now solvent is nonvolatile and carrier gas is insoluble. So, if we have a mixture of say certain component like oxygen and nitrogen, and now we consider nitrogen is inert for the solvent nitrogen is insoluble and oxygen is only soluble, then the other case if we take a solvent which does not vaporize or it considered essentially nonvolatile in nature, then this energy balance will be automatically satisfied or L by G remains you know constant.

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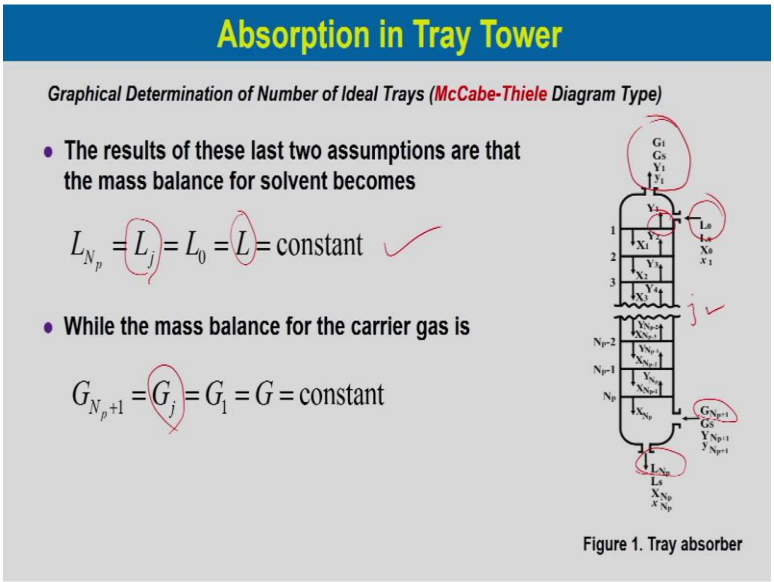

Absorption in Tray Tower

Graphical Determination of Number of Ideal Trays (McCabe-Thiele Diagram Type)

- The results of these last two assumptions are that the mass balance for solvent becomes

$$L_{N_p} = L_j = L_0 = L = \text{constant}$$

- While the mass balance for the carrier gas is

$$G_{N_p+1} = G_j = G_1 = G = \text{constant}$$

Figure 1. Tray absorber

The result of this last two assumptions are that the mass balance is for the solvents, so the liquid flow rates remain constant throughout the column. So, you can see, so L 0 which is entering at the top then at any section of the column J is L j and would be equal to L N p which is coming out and we can call it L as constant. Similarly, the mass balances for the carrier gas now G N p plus 1 which is entering here and then it is know G j at this location and then G 1 at the know first plate and then G which is coming out over here, this is the gas flow rate which is coming out at the exit at top of the column, so that remains constant.

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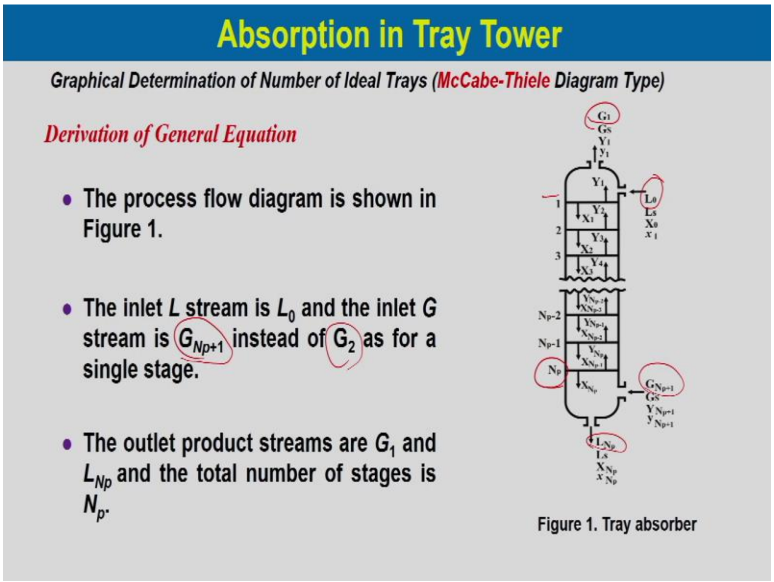

Absorption in Tray Tower

Graphical Determination of Number of Ideal Trays (McCabe-Thiele Diagram Type)

Derivation of General Equation

- The process flow diagram is shown in Figure 1.
- The inlet L stream is L_0 and the inlet G stream is G_{Np+1} instead of G_2 as for a single stage.
- The outlet product streams are G_1 and L_{Np} and the total number of stages is N_p.

Figure 1. Tray absorber

Then the derivation for this you know figure we can write inlet stream L is L naught and the inlet G stream is G N p plus 1. So, L naught and G N p plus 1 that is the inlet conditions instead of G 2 as for the single stage, like in single stage we used G 2 so instead of G N p plus 1. So, bottom we mentioned you know position 2 and top at position 1. So, instead of that it is G N p plus 1.

The product outlet stream is G 1 over here and instead of L N p which is over here. The total number of stages here is considered N p which is number from top 1, 2. N p, so, total number of stages is N p.

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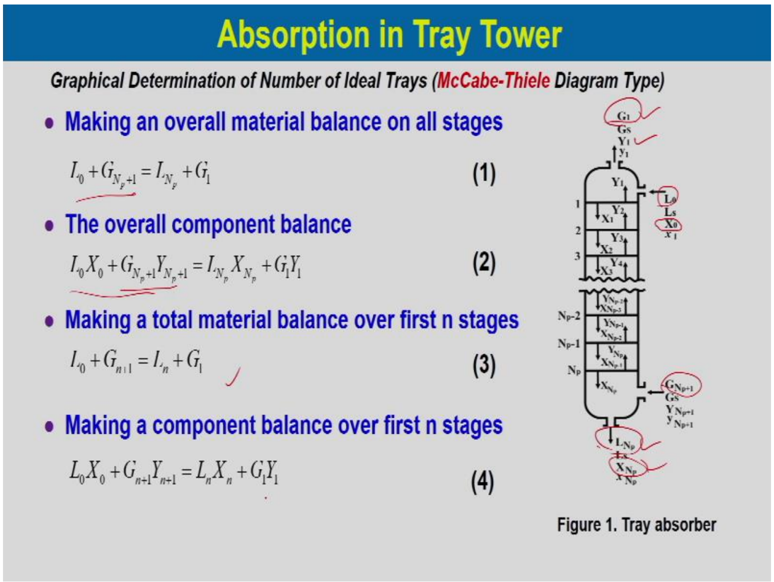

Absorption in Tray Tower

Graphical Determination of Number of Ideal Trays (McCabe-Thiele Diagram Type)

- Making an overall material balance on all stages

$$L_0 + G_{N_p+1} = L_{N_p} + G_1 \qquad (1)$$

- The overall component balance

$$L_0 X_0 + G_{N_p+1} Y_{N_p+1} = L_{N_p} X_{N_p} + G_1 Y_1 \qquad (2)$$

- Making a total material balance over first n stages

$$L_0 + G_{n+1} = L_n + G_1 \qquad (3)$$

- Making a component balance over first n stages

$$L_0 X_0 + G_{n+1} Y_{n+1} = L_n X_n + G_1 Y_1 \qquad (4)$$

Figure 1. Tray absorber

Now, if we do the overall balance on all stages throughout the column, the inlet is L naught and G N p plus one1 so, this one and the exit which is L N p and G 1. So, this is the overall material balance on all stages. Now, if we do the component balance for the species, so of the solute with the inlet liquid we have L naught X naught. And similarly with the inlet gases is plus G N p plus 1 into Y capital Y N p plus 1, so which is over here. So, this is the inlet and the exit composition is L N p into X N p that is over here and then multiplied by G 1 into capital Y 1. So, this is the overall component balance.

Now, making a total material balance over first n stages if we consider any stage n from top then if we do that it would be L naught plus G n plus 1 would be equal to L n plus G 1. Now, making a component balance over that section of the know column for the first n stages, so we would obtain L naught X naught plus G n plus 1 into capital Y n plus 1 is equal to L n X n plus G 1 Y 1; so, this is equation 4.

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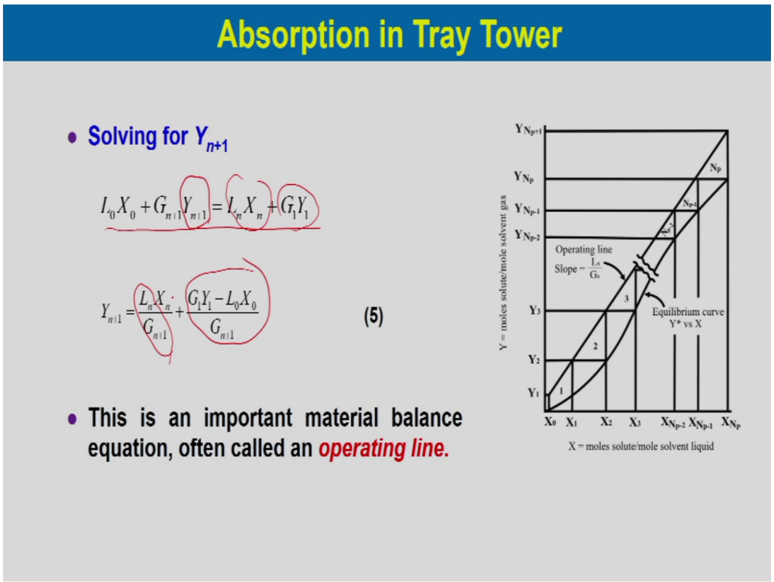

Absorption in Tray Tower

- Solving for Y_{n+1}

$$L_0X_0 + G_{n+1}Y_{n+1} = L_nX_n + G_1Y_1$$

$$Y_{n+1} = \frac{L_nX_n}{G_{n+1}} + \frac{G_1Y_1 - L_0X_0}{G_{n+1}} \qquad (5)$$

- This is an important material balance equation, often called an *operating line.*

Now, if we solve for this equation, so this is our equations we have done for the first n-stages component balance. Now, if we solve for Y n plus 1 we can write Y n plus 1 would be equal to L n, X n plus G 1 Y 1 minus L naught X naught by G n plus 1. So, this is an important material balance equation and it is often called an operating line. So, you can see the operating line has an intercept over here with the no composition G 1 Y 1 minus L naught X naught by G n plus 1. This is the slope of the curve into X n.

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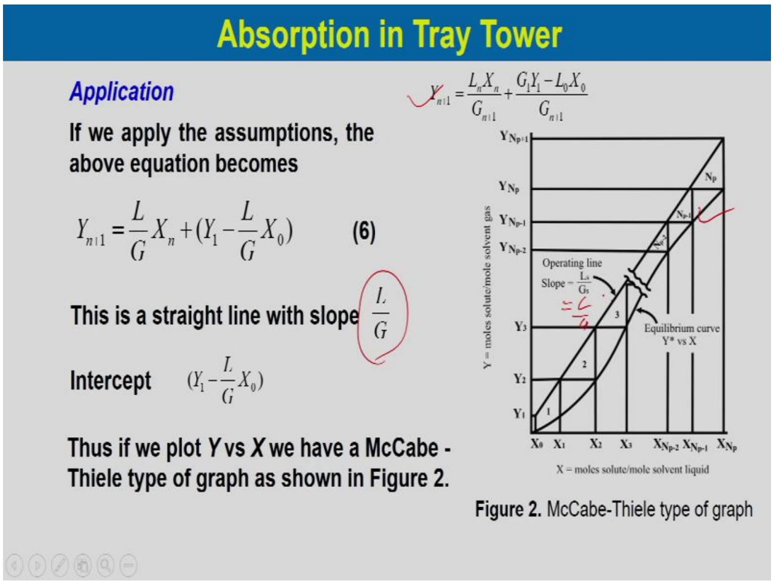

Absorption in Tray Tower

Application

If we apply the assumptions, the above equation becomes

$$Y_{n+1} = \frac{L}{G}X_n + (Y_1 - \frac{L}{G}X_0) \qquad (6)$$

This is a straight line with slope $\frac{L}{G}$

Intercept $(Y_1 - \frac{L}{G}X_0)$

Thus if we plot *Y* vs *X* we have a McCabe - Thiele type of graph as shown in Figure 2.

$$Y_{n+1} = \frac{L_nX_n}{G_{n+1}} + \frac{G_1Y_1 - L_0X_0}{G_{n+1}}$$

Figure 2. McCabe-Thiele type of graph

Now, if we apply the assumption that the above equations becomes Y n plus 1 is equal to L by G X n plus Y 1 minus L by G X naught. So, this is equation 6. And this is a straight line with the slope L by G. Now, intercept as we said intercept is this part Y 1 minus L by G X naught. And thus if we plot Y versus X, we have a McCabe-Thiele type of graph as shown in the figure over here. So, we have the equilibrium curve this one is equilibrium curve and this is no either L s by G s or essentially we can call it L by G. With this slope we have this operating line. This is the operating line equation.

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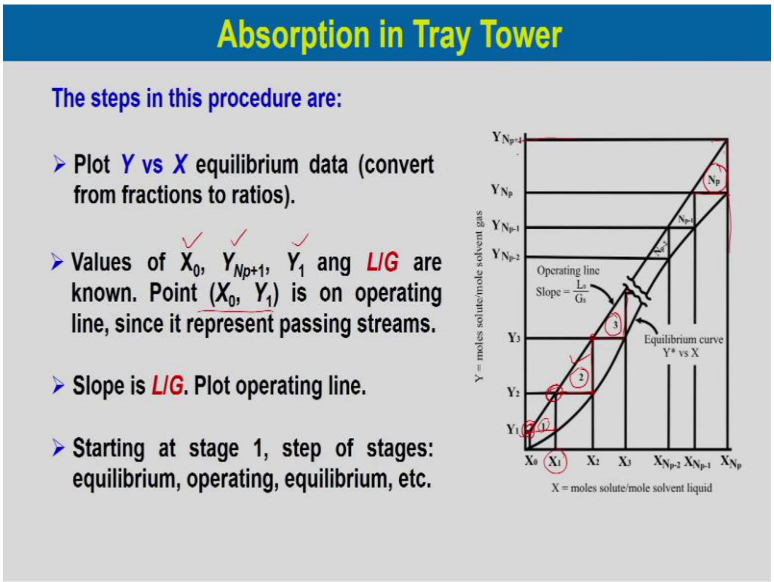

Absorption in Tray Tower

The steps in this procedure are:

- Plot Y vs X equilibrium data (convert from fractions to ratios).
- Values of X_0, Y_{Np+1}, Y_1 ang L/G are known. Point (X_0, Y_1) is on operating line, since it represent passing streams.
- Slope is L/G. Plot operating line.
- Starting at stage 1, step of stages: equilibrium, operating, equilibrium, etc.

And then to find out the number of plates, we need to follow the certain steps plot Y versus X equilibrium data convert into mole fraction to ratios at you can see capital Y and capital X these are plotted over here in mole ratio in it. And then values of X naught, Y N p plus 1, Y 1 and L by G are known. So, all these a point these are the inlet know composition for the liquid, this is inlet composition for the gas, this is the exit composition for the gas and L by G these are known.

So, the point X naught Y 1 that is known on this point. So, operating lines since it represents the passing streams. So, this is known to us. And then slope L by G we know. So, with that we can plot the operating line. We have plotted the equilibrium line here, and we can plot the operating line with this know data then we can calculate the number of stage.

Now, starting from this point, so this is the passing streams at every point or mixing point we can say that mixing point. And from here know what it reads a at a particular plate, it reaches to the equilibrium for the ideal stages. So, from this passing streams, so we need to pass it to the equilibrium line. So, this represents one equilibrium stage or one ideal stage. So, from the mixing point for a particular tray and it moves to the if you move to the equilibrium line and this is one tray, so, this is the first tray.

Now, from this, what will happen this know composition with X 1 liquid and the gases which will pass through that liquid you having the composition of Y 2. So, you move to the you know operating line and then you move to the equilibrium curve with the so this is the mix another mixing point and then you move to the equilibrium curve, so, these two represent the second stage.

So, now in similar way if you just make the staircase arrangement from this mixing point, you go to the equilibrium line and go to the operating line this represents one equilibrium stage. So, similarly you can plot till the exit concentration is reached. And then when you reach the know bottom tray composition, you need to stop to find out the number of trays required, so which is N p over here shown over here.

So, this is N p number of stages and you can see it reaches the bottom of the tower composition which is Y N p plus 1 and X N p. So, this way we can find out graphically using the McCabe-Thiele type of diagram to calculate the number of ideal stage required for a particular separation.

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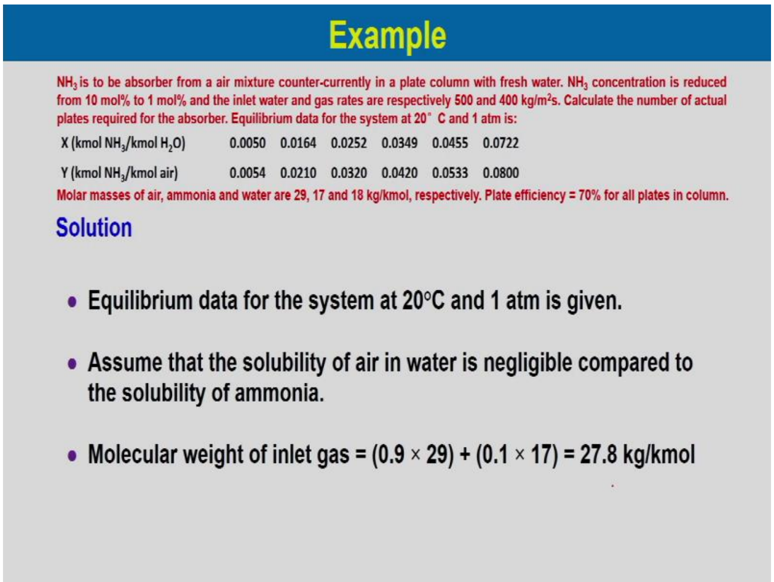

Example

NH_3 is to be absorber from a air mixture counter-currently in a plate column with fresh water. NH_3 concentration is reduced from 10 mol% to 1 mol% and the inlet water and gas rates are respectively 500 and 400 kg/m^{2}s. Calculate the number of actual plates required for the absorber. Equilibrium data for the system at 20° C and 1 atm is:

X (kmol NH_3/kmol H_2O)	0.0050	0.0164	0.0252	0.0349	0.0455	0.0722
Y (kmol NH_3/kmol air)	0.0054	0.0210	0.0320	0.0420	0.0533	0.0800

Molar masses of air, ammonia and water are 29, 17 and 18 kg/kmol, respectively. Plate efficiency = 70% for all plates in column.

Solution

- Equilibrium data for the system at 20°C and 1 atm is given.
- Assume that the solubility of air in water is negligible compared to the solubility of ammonia.
- Molecular weight of inlet gas = (0.9 × 29) + (0.1 × 17) = 27.8 kg/kmol

Let us consider an example to solve this type of problem. So, ammonia is to be absorbed from a air mixture counter-currently in a plate column with fresh water. Ammonia concentration is reduced from 10 mole percent to 1 mole percent and the inlet water and gas rates are respectively 500 and 400 kg per meter square second. Now, we need to calculate the number of actual plate require for an absorber, know equilibrium data for the system is given at 20 degree centigrade and 1 atmosphere pressure it is given capital X and capital Y, these are given. And molar masses of air ammonia and water they are given 29, 17 and 18 kg per k mole. Now, plate efficiency is given 70 percent for all plates in the column. So, now, we need to calculate the actual number of plates required for this separation.

Now, the equilibrium data for the system at 20 degree centigrade and 1 atmosphere pressure is given. Now, assume that the solubility of air in water is negligible compared to the solubility of ammonia. So, air is considered as a inert carrier gas with respect to know ammonia and it is insoluble in water so the compared to the solubility of ammonia. Molecular weight of the inlet gas we can calculate. So, which is 90 percent of air, so it is 0.9 into 29 plus 10 percent of ammonia which is 0.1 into 17, so it is 27.8 kg per k mole.

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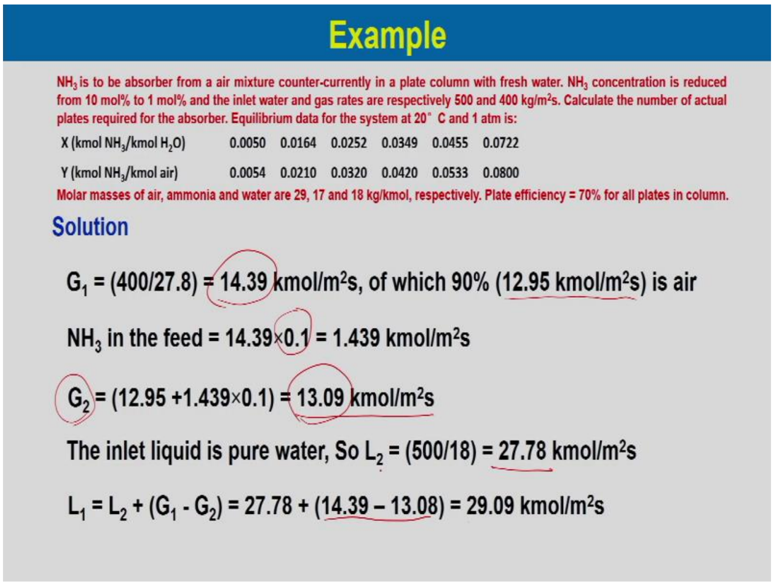

Example

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Molar masses of air, ammonia and water are 29, 17 and 18 kg/kmol, respectively. Plate efficiency = 70% for all plates in column.

Solution

$G_1 = (400/27.8) = 14.39$ kmol/m^{2}s, of which 90% (12.95 kmol/m^{2}s) is air

NH_3 in the feed = $14.39 \times 0.1 = 1.439$ kmol/m^{2}s

$G_2 = (12.95 + 1.439 \times 0.1) = 13.09$ kmol/m^{2}s

The inlet liquid is pure water, So $L_2 = (500/18) = 27.78$ kmol/m^{2}s

$L_1 = L_2 + (G_1 - G_2) = 27.78 + (14.39 - 13.08) = 29.09$ kmol/m^{2}s

Now, we can calculate G 1 which is at the exit stream of top of the column which is 400 divided by 27 average molecular weight is 27.8. So, it is 14.39 kilo mole per meter square second. Now, of this total we have 90 percent is air. So, 90 percent would be

12.95 kilo mole per meter square second is air. Now, ammonia in the feed stream is no 14.39 into 0.1 is the mole fraction of ammonia in the feed stream.

So, it is 1.439 kilo mole per meter square second, so, ammonia in the feed stream. And then this G 2 the gas flow rate G 2 would be 12.95 plus 1.39 into 0.1, so it is 13.09 kilo mole per meter square second. The inlet liquid is pure water. So, L 2 would be 500 by 18, so which is equal to 27.78 kilo mole per meter square second.

So, L 1 would be equal to L 2 plus G 1 minus G 2, so which is essentially 27.78 and 14.39 is your know G 1 and then G 2 is 13.09. So, if we substitute here, so it would be 29.09 kilo mole per meter square second. So, we have the data G 1 L 1 and G 2 and L 2

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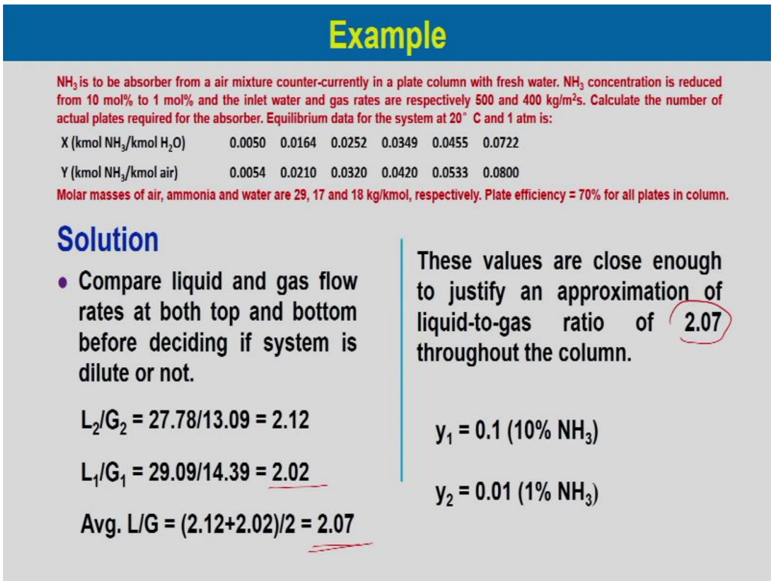

Example

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Molar masses of air, ammonia and water are 29, 17 and 18 kg/kmol, respectively. Plate efficiency = 70% for all plates in column.

Solution

- Compare liquid and gas flow rates at both top and bottom before deciding if system is dilute or not.

$L_2/G_2 = 27.78/13.09 = 2.12$

$L_1/G_1 = 29.09/14.39 = \underline{2.02}$

Avg. $L/G = (2.12+2.02)/2 = \underline{2.07}$

These values are close enough to justify an approximation of liquid-to-gas ratio of 2.07 throughout the column.

$y_1 = 0.1$ (10% NH_3)

$y_2 = 0.01$ (1% NH_3)

Now, compare liquid and gas flow rates at both top and bottom, before deciding if the system is dilute or not. So, if we look into that L 2 by G 2, it is around 27.78 by 13.09, which is 2.12. Similarly, L 1 by G 1 if we divide 29.09 divided by 14.39, which is 2.02. So, if the average if we take average L by G would be 2.12 plus 2.02 divided by 2, which is 2.07. So, essentially L by G is known almost close to each other and we can assume they are constants.

So, these values are close enough to justify an approximation of the liquid-to-gas ratio of 2.07 throughout the column. And y 1 is known, it is 0.1, because 10 percent ammonia. And y 2 is you know 0.01, because it is 1 percent ammonia in the exit stream, so that has to be reduced from 10 mole percent of ammonia to 1 mole percent of ammonia.

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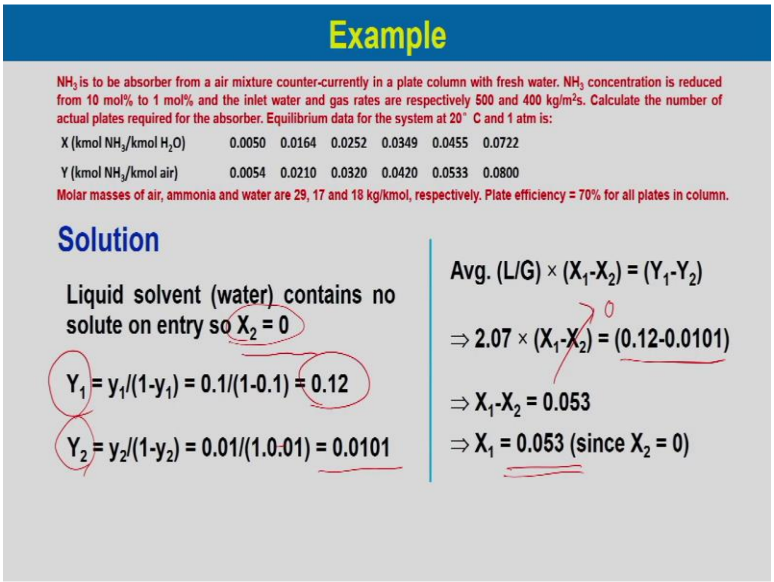

Example

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Molar masses of air, ammonia and water are 29, 17 and 18 kg/kmol, respectively. Plate efficiency = 70% for all plates in column.

Solution

Liquid solvent (water) contains no solute on entry so $X_2 = 0$

$Y_1 = y_1/(1-y_1) = 0.1/(1-0.1) = 0.12$

$Y_2 = y_2/(1-y_2) = 0.01/(1.0.01) = 0.0101$

Avg. $(L/G) \times (X_1-X_2) = (Y_1-Y_2)$

$\Rightarrow 2.07 \times (X_1-\overset{0}{\cancel{X_2}}) = (0.12-0.0101)$

$\Rightarrow X_1-X_2 = 0.053$

$\Rightarrow X_1 = 0.053$ (since $X_2 = 0$)

Now, liquid solvent which is water contents no solute at the entry solvent is solute free. So, X 2 is 0, capital Y 1, we can calculate which is equal to small y 1 divided by 1 minus y 1, which is 0.1 divided by 1 minus 0.1, which is 0.12. And similarly, Y 2 we can calculate is equal to small y 2 divided by 1 minus y 2 and which is essentially 0.01 divided by 1 minus 0.01 and which is essentially 0.0101. So, mole ratio unit capital Y 1, and capital Y 2 is known.

Now, average L by G into X 1 minus X 2 would be equal to Y 1 minus Y 2, this is from the this is mole balance. If we substitute average L by G, which is 2.07 into X 1 minus X 2 would be equal to 0.12 minus 0.0101. From here and also as the entry is the solvent is solute free, so it is X 2 would be essentially 0. We will have X 1 minus X 2 would be these X 1 would be 0.053. So, X 1 is now calculated capital X 1 and capital X 2 is known.

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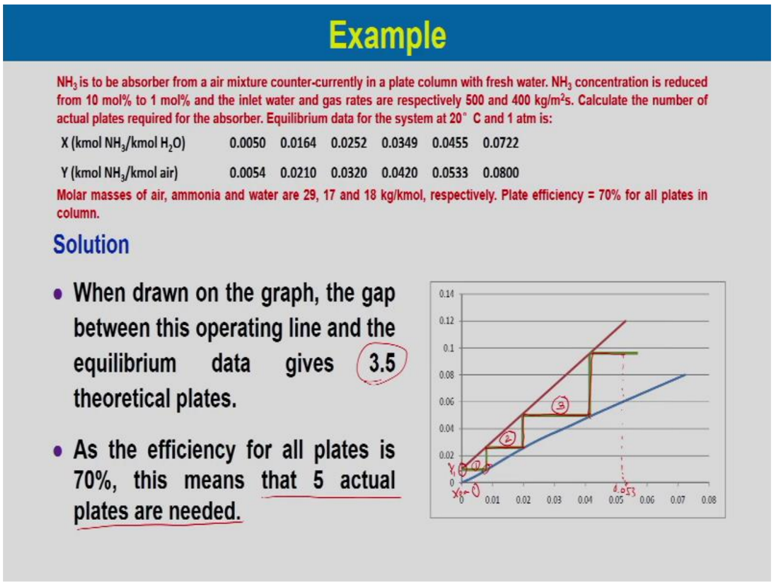

Example

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Molar masses of air, ammonia and water are 29, 17 and 18 kg/kmol, respectively. Plate efficiency = 70% for all plates in column.

Solution

- When drawn on the graph, the gap between this operating line and the equilibrium data gives 3.5 theoretical plates.
- As the efficiency for all plates is 70%, this means that 5 actual plates are needed.

When drawn on the graph, the gap between the operating line and the equilibrium data gives 3.5 theoretical plate. So, you can just look into the graph and you have the initial point which is you know capital X naught, which is basically X 2 is 0, Y 1 which is somewhere here. So, this is Y 1, so this point is known. And final composition, it will go to 0.053. So, you start from here. And then move to the equilibrium curve from the mixing point. So, this is one equilibrium stage.

Then move to the operating line and again move to the equilibrium curve. So, you will have another ideal stages and similar procedure you can follow. So, you will have another the third stage. And then you can move and you can go to the exit stream composition that is 0.053 and we can consider this half plate from the graph. So, essentially, we will get 3.5 stage.

Now, as the efficiency for the plate is 70 percent, so the number of real trays required. So, each plate is having the efficiency of 0.7, 70 percent efficiency. The ideal plate divided by 0.7 is the actual plate required to perform this job. So, essentially it will give 5 actual plates needed for the separation. So, this is how we can use the McCabe-Thiele method to calculate the number of ideal plates and then we can calculate number of actual plate required for a given job.

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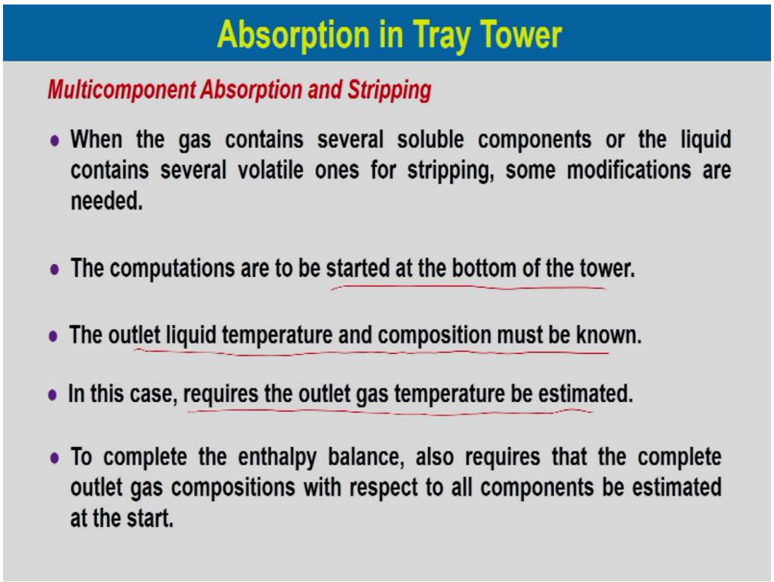

Absorption in Tray Tower

Multicomponent Absorption and Stripping

- When the gas contains several soluble components or the liquid contains several volatile ones for stripping, some modifications are needed.
- The computations are to be started at the bottom of the tower.
- The outlet liquid temperature and composition must be known.
- In this case, requires the outlet gas temperature be estimated.
- To complete the enthalpy balance, also requires that the complete outlet gas compositions with respect to all components be estimated at the start.

Let us move to the absorption in tray tower, for multicomponent absorption as also a stripping. Now, when the gas content several soluble components or the liquid contains several volatile once for stripping, some modifications are needed. So, we cannot use the same method as we have done for the single component systems. The computational are to be started at the bottom of the tower. So, we have to start the computation at the bottom of the tower. And the outlet liquid temperature and the composition must be known that is required to start the calculation for the multicomponent system.

So, in this case, it requires the outlet gas temperature be estimated. So, based on this known outlet liquid and composition, we can calculate the outlet gas temperature, so which is going at the top? So, our calculation starts at the bottom, where we need the outlet liquid exit for counter current absorption tower, the liquid exit at the bottom. So, its temperature and composition is known.

If you proceed to the gas exit at the top of the column, then we need to estimate the temperature which is showing out at top of the tower. So, to complete the enthalpy balance, it also requires that the complete outlet gas composition with respect to all components be estimated at the start. If that is there, so then we can complete the enthalpy balance equation.

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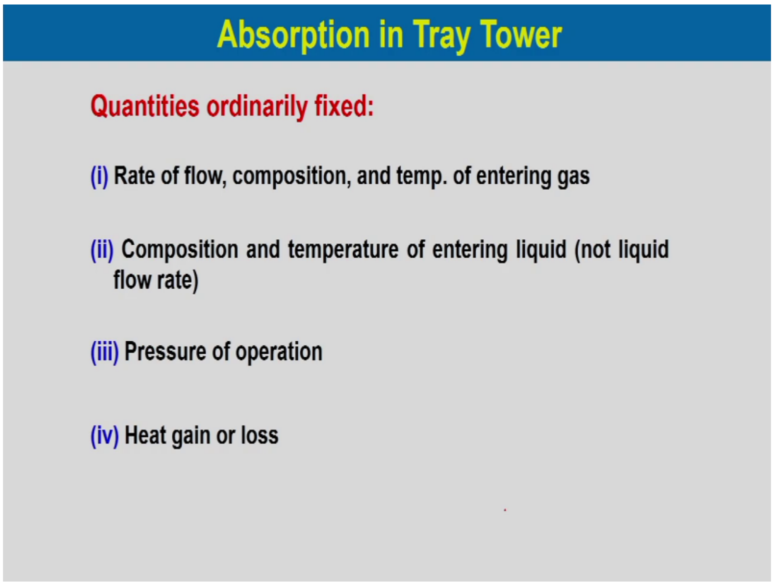

Absorption in Tray Tower

Quantities ordinarily fixed:

(i) Rate of flow, composition, and temp. of entering gas

(ii) Composition and temperature of entering liquid (not liquid flow rate)

(iii) Pressure of operation

(iv) Heat gain or loss

The quantity which are generally fixed for this design are the rate of flow, composition, and temperature of the entering gas. The second thing which is fixed is composition and temperature of the entering liquid, not the liquid flow rate. The pressure of operation at which it will be operated, and the heat gain or loss.

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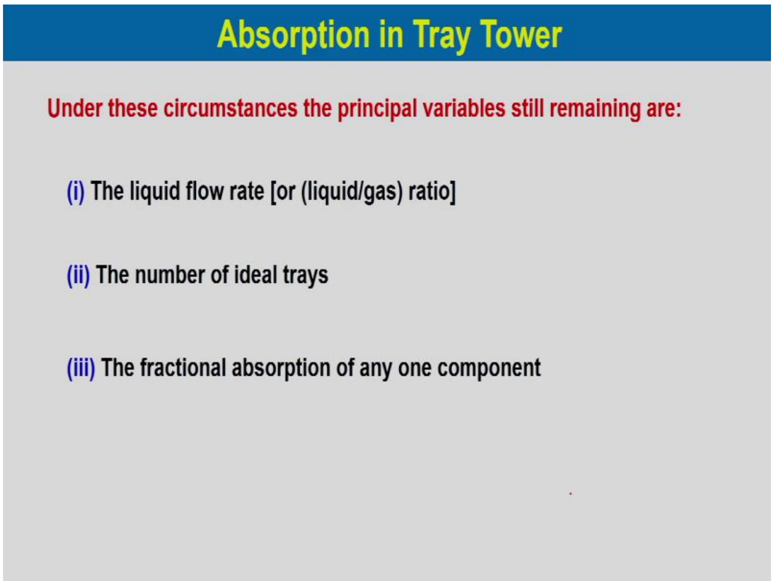

Absorption in Tray Tower

Under these circumstances the principal variables still remaining are:

(i) The liquid flow rate [or (liquid/gas) ratio]

(ii) The number of ideal trays

(iii) The fractional absorption of any one component

Under these circumstances the principal variable still remaining, which are highlighted here the liquid flow rate or the L by G ratio, either liquid flow rate or L by G ratio should be remaining which has to be estimated. The number of ideal trays required for the separation. And then the fractional absorption of any one component, since it is multicomponent absorption or stripping. The fractional absorption of a particular component has to be known or it is a principal variable over here.

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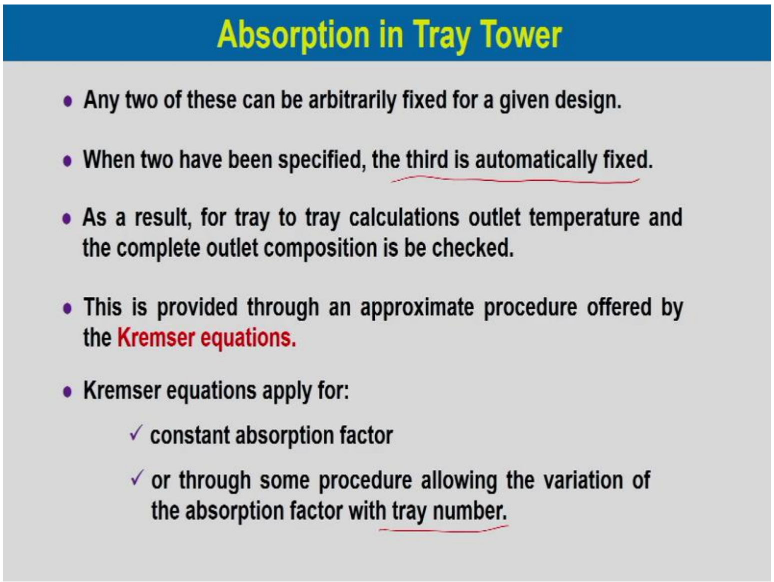

Absorption in Tray Tower

- Any two of these can be arbitrarily fixed for a given design.
- When two have been specified, the third is automatically fixed.
- As a result, for tray to tray calculations outlet temperature and the complete outlet composition is be checked.
- This is provided through an approximate procedure offered by the Kremser equations.
- Kremser equations apply for:
  - ✓ constant absorption factor
  - ✓ or through some procedure allowing the variation of the absorption factor with tray number.

So, now among these three, if any two can be arbitrarily fixed for a given design. So, when the two have been specified, the third is automatically fixed. So, now out of these three know variables, if we can decide any two, the third will be automatically fixed. So, as a result, for tray to tray calculation outlet temperature and the complete outlet composition is to be checked.

So, we need to have a arbitrarily fixed design parameters, we need to have a an approximate procedure to get those data to be fixed. And this is provided through an appropriate procedure offered by the Kremser equation. So, Kremser equation apply for constant absorption factor as we have discussed before. And or through some procedure which allow the variation of the absorption factor with tray number, either constant absorption factor or there would be some procedure, which will allow the variation of the absorption factor from tray to tray and it is for each component.

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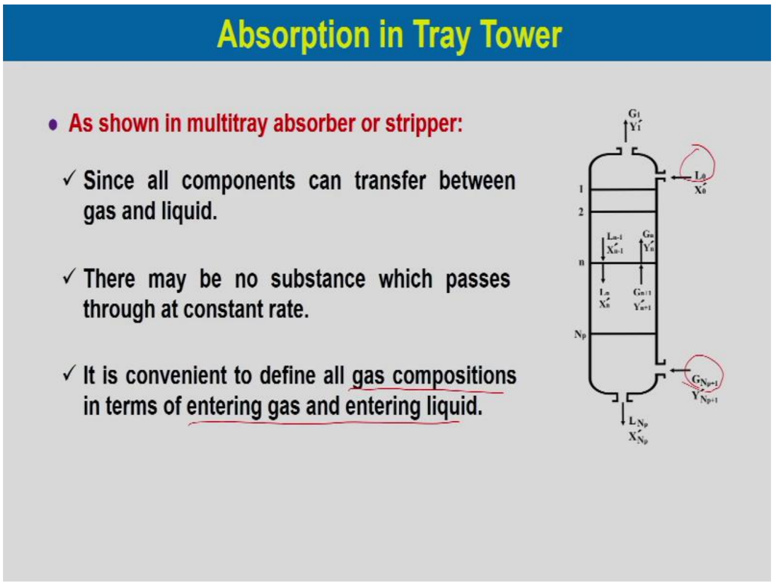

Absorption in Tray Tower

- As shown in multitray absorber or stripper:
  - ✓ Since all components can transfer between gas and liquid.
  - ✓ There may be no substance which passes through at constant rate.
  - ✓ It is convenient to define all gas compositions in terms of entering gas and entering liquid.

So, over here this is know multitray absorber or stripper. Similar to the one, we have shown earlier. Since all components can transfer between the gas and liquid. So, there may be no substance which passes through a constant rate, so because all the substances are transferring from one phase to the other. So, the constant rate for each substance know may not be there, so that is why, it is very convenient. If we define the gas composition in terms of the entering gas and entering liquid, so all the composition if we can define with the entering gas and liquid composition which are known to us, then it would be easier to compute.

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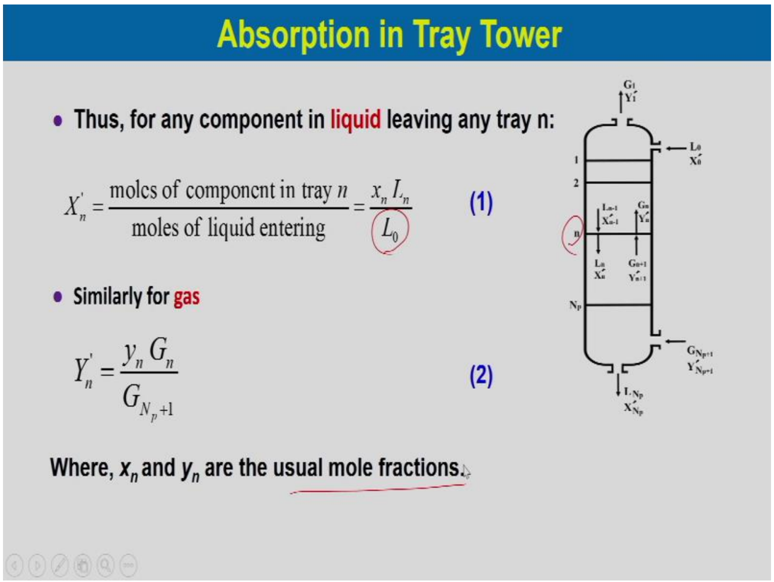

Absorption in Tray Tower

- Thus, for any component in liquid leaving any tray n:

$$X_n' = \frac{\text{molcs of componcnt in tray } n}{\text{moles of liquid entering}} = \frac{x_n L_n}{L_0} \qquad (1)$$

- Similarly for gas

$$Y_n' = \frac{y_n G_n}{G_{N_p+1}} \qquad (2)$$

Where, x_n and y_n are the usual mole fractions.

Thus for any component in liquid leaving any tray n, so over here. We can define X n dash is the mole of component in tray n divided by the moles of liquid entering. So, know moles of component know particular component in tray n, if we considered x n and with a liquid flow rate L n divided by L naught is the know entering a liquid feed flow rate, so this is X n dash.

Similarly, for the gas it is capital Y n dash would be equal to small y n G n divided by G N p plus 1. So, this is known X n dash and Y n dash, these are defined based on the inlet flow rate which is known for the liquid and the gas. So, small x n and small y n are the usual mole fractions over here.

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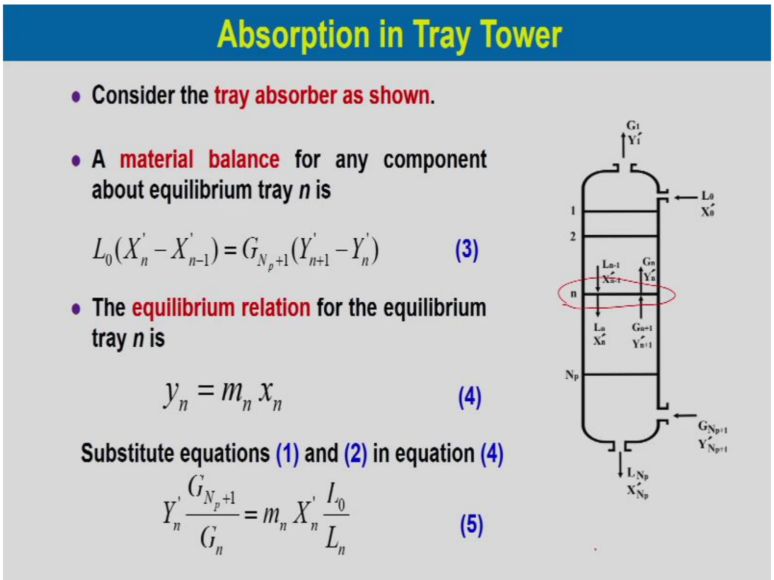

Absorption in Tray Tower

- Consider the tray absorber as shown.
- A material balance for any component about equilibrium tray *n* is

$$L_0(X'_n - X'_{n-1}) = G_{N_p+1}(Y'_{n+1} - Y'_n) \qquad (3)$$

- The equilibrium relation for the equilibrium tray *n* is

$$y_n = m_n x_n \qquad (4)$$

Substitute equations (1) and (2) in equation (4)

$$Y'_n \frac{G_{N_p+1}}{G_n} = m_n X'_n \frac{L_0}{L_n} \qquad (5)$$

Now, consider the tray absorber as shown over here. And if you do a material balance for any component about the equilibrium tray n, so this one, so we can write L naught X n dash minus X n minus 1 dash would be equal to G N p plus 1 into Y n plus 1 dash minus Y n dash. So, this is the know material balance for any component about an equilibrium tray n. Now, the equilibrium relation for the equilibrium tray n is we can write small y n would be equal to m n x n.

So, now if we substitute equation 1 and equation 2 in equation 4, equation 1 and equation 2 is basically the know mole ratio, we have calculated based on the known inlet flow rates. So, if you substitute in equation 4 over here, so we will essentially get capital Y n dash G N p plus 1 by G n would be equal to m n X n dash into L naught by L n.

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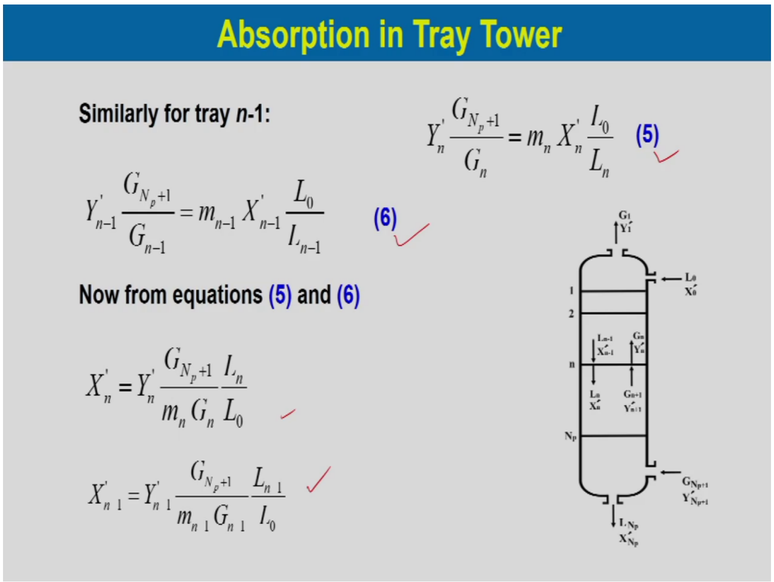

Absorption in Tray Tower

Similarly for tray *n*-1:

$$Y'_n \frac{G_{N_p+1}}{G_n} = m_n X'_n \frac{L_0}{L_n} \quad (5)$$

$$Y'_{n-1} \frac{G_{N_p+1}}{G_{n-1}} = m_{n-1} X'_{n-1} \frac{L_0}{L_{n-1}} \quad (6)$$

Now from equations (5) and (6)

$$X'_n = Y'_n \frac{G_{N_p+1}}{m_n G_n} \frac{L_n}{L_0}$$

$$X'_{n-1} = Y'_{n-1} \frac{G_{N_p+1}}{m_{n-1} G_{n-1}} \frac{L_{n-1}}{L_0}$$

Now, similarly for n minus 1 tray, we can write Y n minus 1 dash G N p plus 1 by G n minus 1 would be equal to m n minus 1 into X n minus 1 into L naught by L n minus 1. Now, from equation 5 and 6, so this is equation 5 and this is equation 6. So, from 5 and 6, we can write X n dash would be equal to Y n dash G N p plus 1 divided by m n G n into L n by L naught. And X n minus 1 dash would be equal to Y n minus 1 dash G N p plus 1 divided by m n minus 1 into G n minus 1 whole into L n minus 1 by L naught. After rearrangement of these two equations, we can write this.

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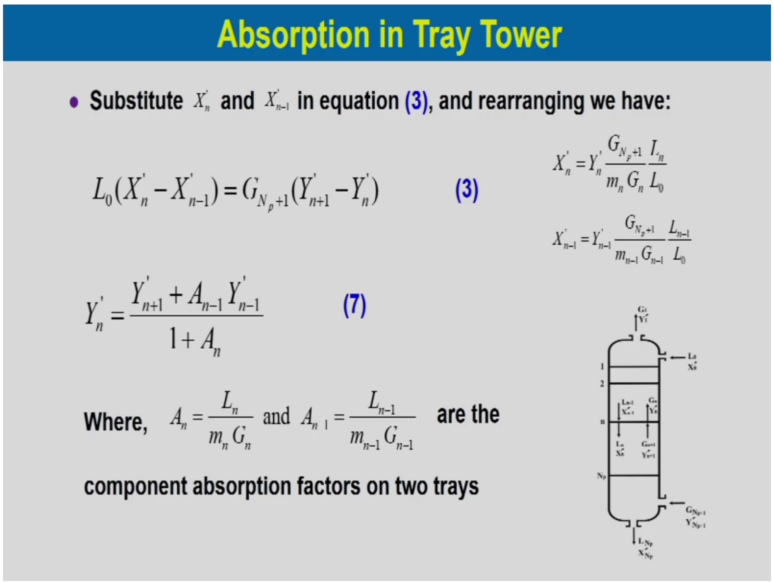

Absorption in Tray Tower

- **Substitute X'_n and X'_{n-1} in equation (3), and rearranging we have:**

$$L_0(X'_n - X'_{n-1}) = G_{N_p+1}(Y'_{n+1} - Y'_n) \quad (3)$$

$$X'_n = Y'_n \frac{G_{N_p+1}}{m_n G_n} \frac{L_n}{L_0}$$

$$X'_{n-1} = Y'_{n-1} \frac{G_{N_p+1}}{m_{n-1} G_{n-1}} \frac{L_{n-1}}{L_0}$$

$$Y'_n = \frac{Y'_{n+1} + A_{n-1} Y'_{n-1}}{1 + A_n} \quad (7)$$

Where, $A_n = \frac{L_n}{m_n G_n}$ and $A_{n-1} = \frac{L_{n-1}}{m_{n-1} G_{n-1}}$ **are the component absorption factors on two trays**

Now, if we substitute the X n dash and X n minus 1 dash in equation 3 and then we rearrange the same. So, this is X n dash and this is X n minus 1 dash as we have derived before, this is the equation 3. Now, if we substitute these two know, it will give Y n dash would be equal to Y n plus 1 dash plus A n minus 1 into Y n minus 1 dash divided by 1 plus A n. In this case, A n is equal to L n by m n G n and A n minus 1 is L n minus 1 by m n minus 1 into G n minus 1. So, these are the know component of absorption factors on two trays for A n an A n minus 1. So, nth tray absorption factor and n minus 1th tray absorption factor.

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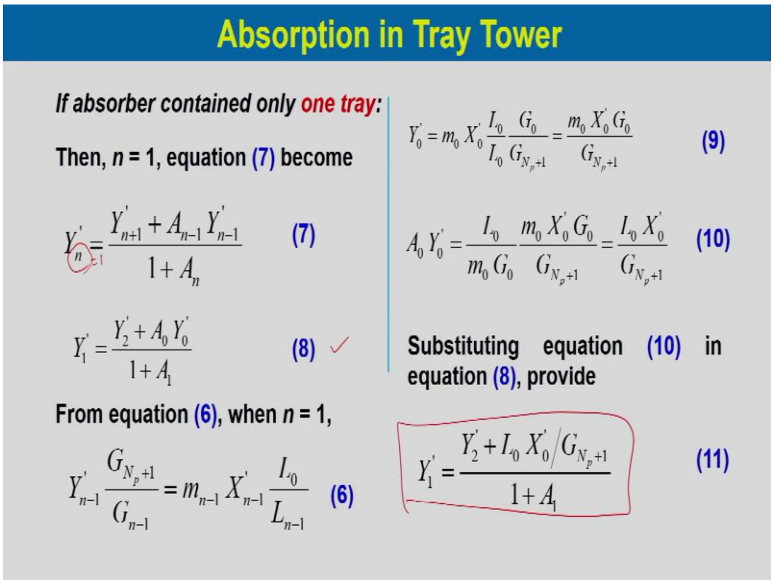

Absorption in Tray Tower

If absorber contained only one tray:

Then, $n = 1$, equation (7) become

$$Y'_{n=1} = \frac{Y'_{n+1} + A_{n-1} Y'_{n-1}}{1 + A_n} \qquad (7)$$

$$Y'_1 = \frac{Y'_2 + A_0 Y'_0}{1 + A_1} \qquad (8) \checkmark$$

From equation (6), when $n = 1$,

$$Y'_{n-1} \frac{G_{N_p+1}}{G_{n-1}} = m_{n-1} X'_{n-1} \frac{L_0}{L_{n-1}} \qquad (6)$$

$$Y'_0 = m_0 X'_0 \frac{L_0}{L_0} \frac{G_0}{G_{N_p+1}} = \frac{m_0 X'_0 G_0}{G_{N_p+1}} \qquad (9)$$

$$A_0 Y'_0 = \frac{L_0}{m_0 G_0} \frac{m_0 X'_0 G_0}{G_{N_p+1}} = \frac{L_0 X'_0}{G_{N_p+1}} \qquad (10)$$

Substituting equation (10) in equation (8), provide

$$\boxed{Y'_1 = \frac{Y'_2 + L_0 X'_0 / G_{N_p+1}}{1 + A_1}} \qquad (11)$$

For absorber which contains only one tray, if n is equal to 1, say equation 7 becomes this is equation 7 and from this we can write it is Y 1 dash would be equal to Y 2 dash plus A naught into Y naught dash divided by 1 plus A 1. So, just substitute n with 1, then from 7, we can get equation 8.

Now, from equation 6, when n is equal to 1, we can write so this is the equation 6. And when n is equal to 1, we can get Y naught dash would be equal to m naught X naught dash L naught by L naught into G not by G N p plus 1, which is equal to m naught X naught dash G naught by G N p plus 1. We can now write A naught Y naught dash is equal to L naught by m naught G naught into m naught X naught dash G naught divided by G N p plus 1, which is equal to L naught X naught dash divided by G N p plus 1. So, substituting this equation 10 in equation 8 over here if we substitute, then we will obtain equation 11 which is Y 1 dash would be equal to Y 2 dash plus L naught X naught dash divided by G N p plus 1 by 1 plus A 1. So, this is you know Y 1 dash.

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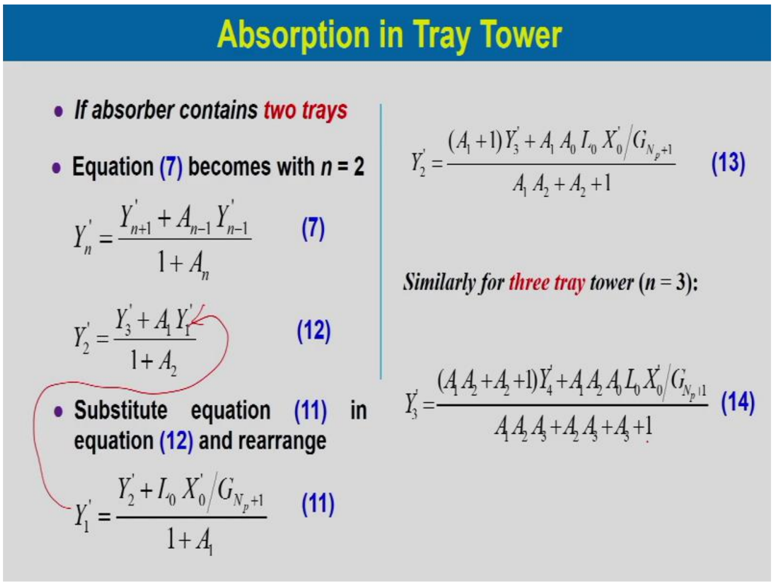

Absorption in Tray Tower

- *If absorber contains two trays*
- Equation (7) becomes with $n = 2$

$$Y'_n = \frac{Y'_{n+1} + A_{n-1} Y'_{n-1}}{1 + A_n} \quad (7)$$

$$Y'_2 = \frac{Y'_3 + A_1 Y'_1}{1 + A_2} \quad (12)$$

- Substitute equation (11) in equation (12) and rearrange

$$Y'_1 = \frac{Y'_2 + L_0 X'_0 / G_{N_p+1}}{1 + A_1} \quad (11)$$

$$Y'_2 = \frac{(A_1 + 1) Y'_3 + A_1 A_0 L_0 X'_0 / G_{N_p+1}}{A_1 A_2 + A_2 + 1} \quad (13)$$

Similarly for three tray tower ($n = 3$):

$$Y'_3 = \frac{(A_1 A_2 + A_2 + 1) Y'_4 + A_1 A_2 A_0 L_0 X'_0 / G_{N_p+1}}{A_1 A_2 A_3 + A_2 A_3 + A_3 + 1} \quad (14)$$

And then similarly, if we just proceed for two trays, so we will just substitute in the same equation 7 with n is equal to 2. And know essentially you will obtain Y 2 dash, this is the substitute equation 11 in equation 12 which we have obtained, this is equation 11 which we have derived for Y 1 dash. So, substitute this Y 1 dash into this, so you will essentially obtain this relation equation 13.

And similarly, for three tray tower n is equal to 3 and you will obtain the equation 14. So, as you can see it will be Y 3 dash would be equal to A 1 A 2 plus A 2 plus 1 Y 4 dash plus A 1 A 2 A naught into L naught into X 0 X naught dash divided by G N p plus 1 divided by A 1 A 2 into A 3 plus A 2 into A 3 plus A 3 plus 1.

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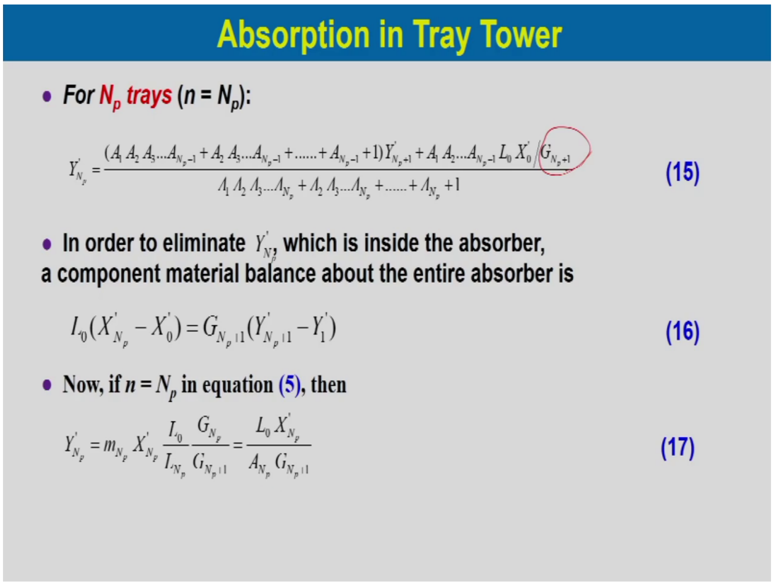

Absorption in Tray Tower

- *For N*

So, similarly for N p trays, n is equal to N p for know all the trays in a tray column of N p number of trays. If we substitute, we will obtain know Y N p dash, so which is you know based on the know, the inlet gas composition and the liquid composition with the absorption factor, we can know relate with them. So, in order to eliminate Y N p over here, which is inside the absorber. A component material balance about the entire absorber is required, so which is know over here. So, this is the entire absorption tower know component balance. And if n is equal to N p in equation 5, then we can write this is Y N p dash, so this is the equation.

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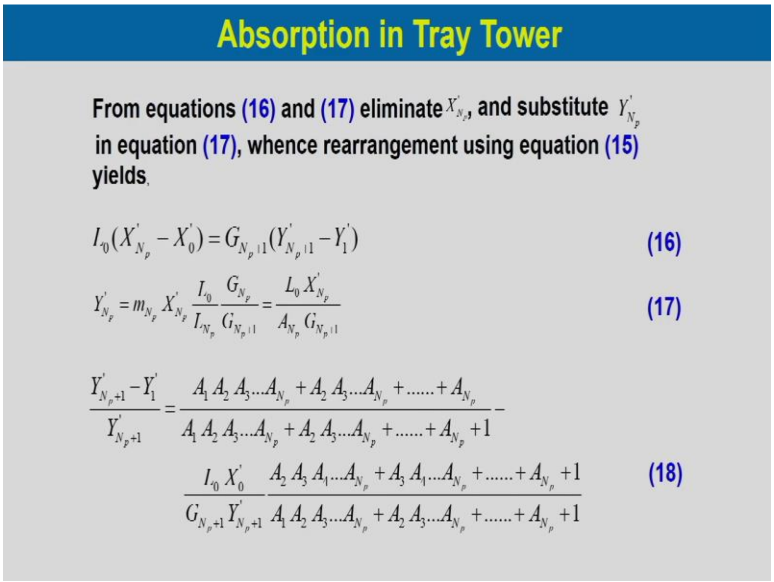

And then from equation 16 and 17, this is equation 16 and 17 eliminate X N p and substitute Y N p dash in equation 17, so this is equation 17. And know if you do the rearrangements of you know using equation 15, so we will have the equation 18, which is know free from any composition inside the column.

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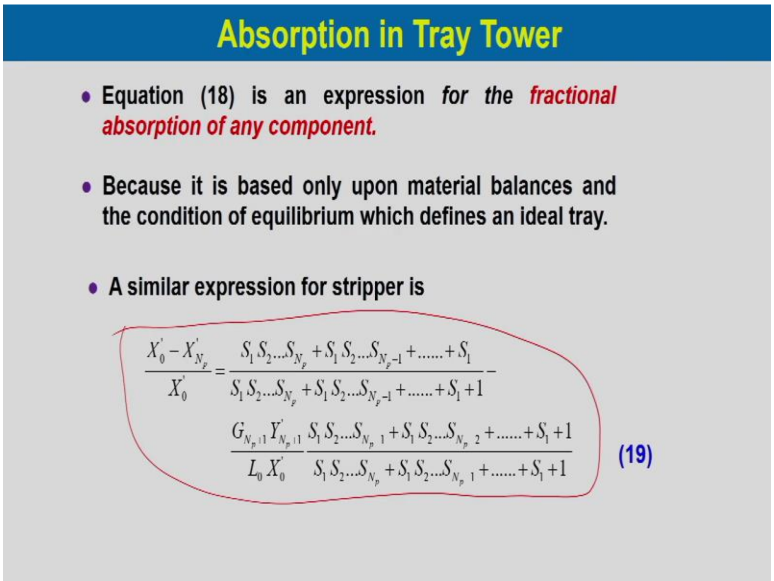

Absorption in Tray Tower

- Equation (18) is an expression *for the fractional absorption of any component.*
- Because it is based only upon material balances and the condition of equilibrium which defines an ideal tray.
- A similar expression for stripper is

$$\frac{X_0^{'}-X_{N_p}^{'}}{X_0^{'}}=\frac{S_1 S_2 ... S_{N_p}+S_1 S_2 ... S_{N_p-1}+......+S_1}{S_1 S_2 ... S_{N_p}+S_1 S_2 ... S_{N_p-1}+......+S_1+1}-\frac{G_{N_p 11} Y_{N_p 11}^{'}}{L_0 X_0^{'}}\frac{S_1 S_2 ... S_{N_p\ 1}+S_1 S_2 ... S_{N_p\ 2}+......+S_1+1}{S_1 S_2 ... S_{N_p}+S_1 S_2 ... S_{N_p\ 1}+......+S_1+1} \quad (19)$$

So, this equation 18 over here, so this equation. So, this is know is an expression for the fractional absorption of any components, because it is based only upon the material balance and the condition of equilibrium which defines an ideal tray. A similar expression for the stripper would be like this S 1and S 2 up to S N p and S N p minus 1, these are the stripping factor. And just inverse of the absorption factor and this is also based on the liquid compositions outside the tower.

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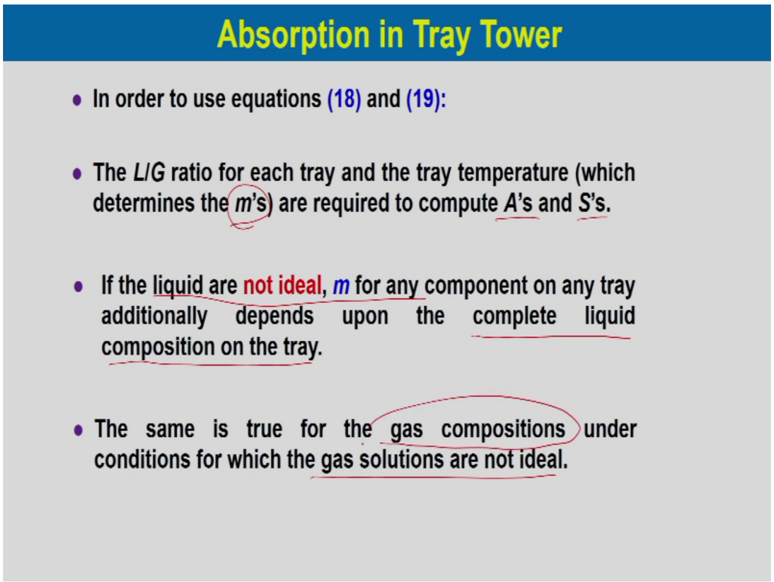

Absorption in Tray Tower

- In order to use equations (18) and (19):
- The *L*/*G* ratio for each tray and the tray temperature (which determines the *m*'s) are required to compute *A*'s and *S*'s.
- If the liquid are not ideal, *m* for any component on any tray additionally depends upon the complete liquid composition on the tray.
- The same is true for the gas compositions under conditions for which the gas solutions are not ideal.

So, in order to use equation 18 and 19, what we need the L by G ratio for each tray and the tray temperature, which determines the m's the equilibrium the Henry's constant and it is also required to compute A's and S's that is absorption factor and stripping factor. If the liquid are not ideal, m for any component on any tray additionally depends upon the complete liquid composition.

So, if liquid are not ideal that will also depend on the complete liquid composition on that tray. The same is true for the gas composition under condition for which the gas solutions are not ideal. So, if also the gas phase are not ideal not only liquid, the same features will also valid for the no it depends on the gas composition as well.

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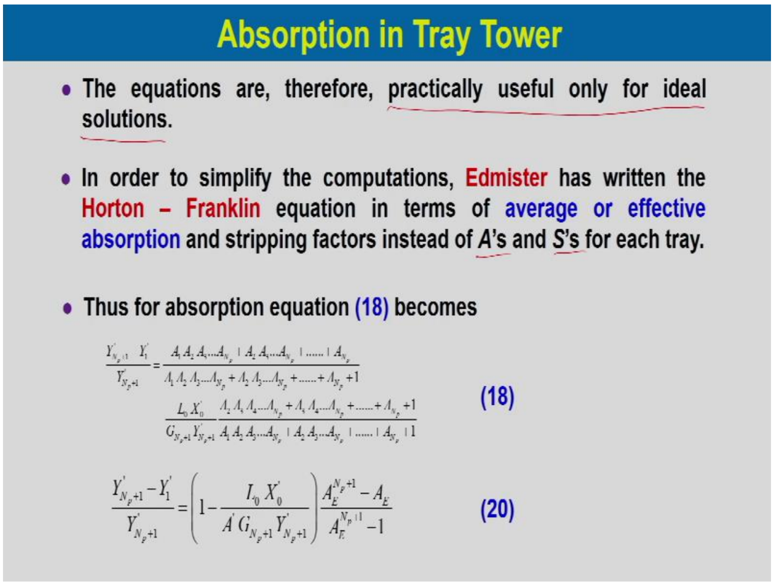

Absorption in Tray Tower

- The equations are, therefore, practically useful only for ideal solutions.
- In order to simplify the computations, Edmister has written the Horton – Franklin equation in terms of average or effective absorption and stripping factors instead of *A*'s and *S*'s for each tray.
- Thus for absorption equation (18) becomes

$$\frac{Y'_{N_p+1}-Y'_1}{Y'_{N_p+1}}=\frac{A_1A_2A_3\ldots A_{N_p}+A_2A_3\ldots A_{N_p}+\ldots\ldots+A_{N_p}}{A_1A_2A_3\ldots A_{N_p}+A_2A_3\ldots A_{N_p}+\ldots\ldots+A_{N_p}+1}-\frac{L_0X'_0}{G_{N_p+1}Y'_{N_p+1}}\frac{A_2A_3A_4\ldots A_{N_p}+A_3A_4\ldots A_{N_p}+\ldots\ldots+A_{N_p}+1}{A_1A_2A_3\ldots A_{N_p}+A_2A_3\ldots A_{N_p}+\ldots\ldots+A_{N_p}+1} \quad (18)$$

$$\frac{Y'_{N_p+1}-Y'_1}{Y'_{N_p+1}}=\left(1-\frac{L_0X'_0}{A'G_{N_p+1}Y'_{N_p+1}}\right)\frac{A_E^{N_p+1}-A_E}{A_E^{N_p+1}-1} \quad (20)$$

The equations are, therefore practically useful only for the ideal solutions. So, this should be remembered that this is practically useful only for ideal solutions. Now, in order to simplify the computation, know Edmister has written the Horten-Franklin equation in terms of the average or effective absorption and stripping factor instead of know variable A's and S's, so absorption factor and stripping factor for each tray.

So, if we can use the average absorption factor or stripping factor, then it would be know simplify the computation. Thus for the absorption equation 18 which becomes like this, this is equation 18. And this can be written as like this Y N p plus 1 dash minus Y 1 dash divided by Y dash N p plus 1 would be equal to 1 minus L naught X naught dash divided by A dash G N p plus 1 into Y N p plus 1 and whole into A E to the power N p plus 1 minus A E divided by A E to the power N p plus 1 minus 1. So, A E is the average or effective absorption factor over here.

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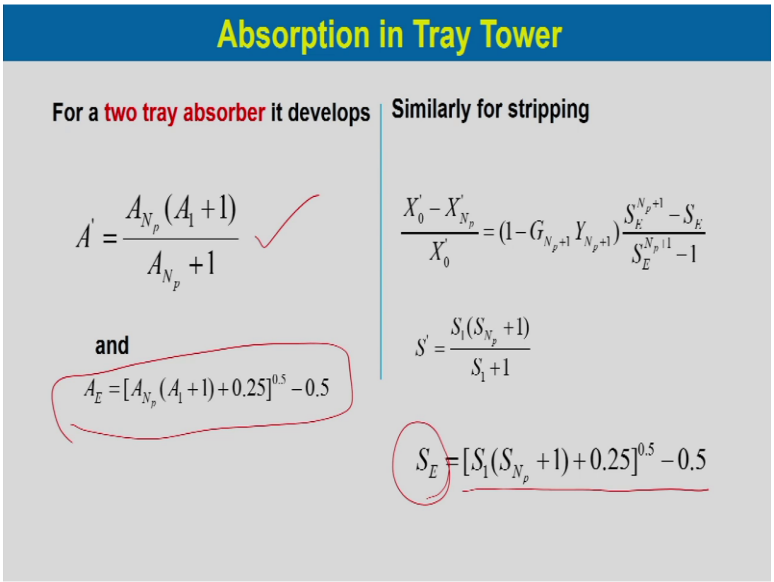

Absorption in Tray Tower

For a **two tray absorber** it develops

$$A' = \frac{A_{N_p}(A_1+1)}{A_{N_p}+1}$$

and

$$A_E = [A_{N_p}(A_1+1)+0.25]^{0.5} - 0.5$$

Similarly for stripping

$$\frac{X'_0 - X'_{N_p}}{X'_0} = (1 - G_{N_p+1} Y_{N_p+1}) \frac{S_E^{N_p+1} - S_E}{S_E^{N_p+1} - 1}$$

$$S' = \frac{S_1(S_{N_p}+1)}{S_1+1}$$

$$S_E = [S_1(S_{N_p}+1)+0.25]^{0.5} - 0.5$$

Similarly, know for a two tray absorber, it develops this equation. And know effective absorption factor or average absorption factor can be know defined like this. Similarly for stripping, we can obtain this relation for using the average stripping factor and X dash can be written over here. So, this is for the stripping column design and this is for the plate towers using effective absorption factor. And this is for the tray column design for multicomponent systems.

And S E is the effective stripping factor which is given over here, after the simplification. With this method the simplify design, which is presented over here for the multicomponent systems. And this is only valid for the ideal solutions. These are know basically the simplified procedure and you can learn more on the know if it is non-ideal system both gas and liquid phase and how to do the computation for that.

So, thank you for attending this lecture, we will continue our discussion on the mass transfer operation for the next module which is module 5 and that would be our final module for distillation.