

Mass Transfer II
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Lecture No. # 13
Mass Transfer II

So, in today's lecture, we take one more example on absorption, before we moving on, before moving on to this distillation, the second unit operation for this course. So, this example will also address some of the fundamental aspects of absorption.

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Example

$G'_2 = 10 \frac{\text{kmol}}{\text{hr} \cdot \text{m}^2}$
 8% SO_2
 $y_1 = 0.08$, $Y_1 = 0.087$
 $G'_S = G'_1(1 - y_1) = 9.2 \text{ units}$

$L' = 30 \frac{\text{kmol}}{\text{hr} \cdot \text{m}^2}$
 $x_2 = x_1 = 0$

$y_2 = 0.026$
 97% to be removed

$y = 2.5x + 4.5x^2$

1. Cal m_1 = solvent flow rate
2. $X_1 = ?$ (spare liquid)
3. Cal 'A' at $x = 0.02$
4. Cal Δy = driving force for mass transfer (gas phase)

$K_y (K_x) = 12 \frac{\text{kmol}}{\text{m}^2 \cdot \text{hr} \cdot \Delta y'}$
 $K_{g_y} (K_g) = 0.15 \frac{\text{kmol}}{\text{m}^2 \cdot \text{hr} \cdot \Delta y}$

So, let us see this example here, where we have a packed column. So, this is a packed column. And this is a gas in at a flow rate of 10 kilo mole per hour per meter square. So, note this superscript here - ((prim)) - because of flow rate is expressed in terms of meter square per meter square cross-sectional area. So, this is a packed bed absorption column. This gas contains 8 percent of certain gas, let us say sulphur dioxide, which means y 1 is given as 0.08 mole fractions and capital Y 1 can be calculated to be 0.087. And G prime is a total flow rate 10 kilo mole per hour per meter square.

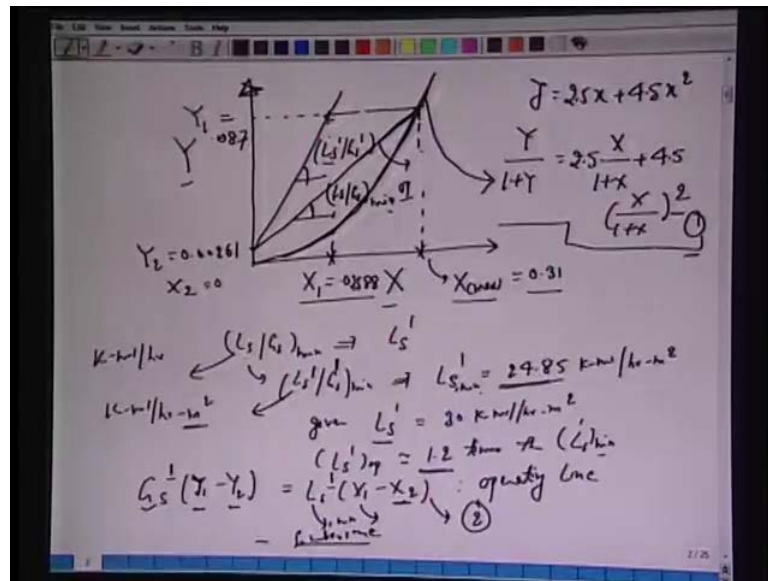
So, we can have molar flow rate of the solvent or the solute free basis, a G prime 1 minus y 1 equal to 9.2 units. So, this unit is same as what we have written here, 10 kilo mole per hour per meter square. So, this gas sulphur dioxide has to be clean with a solvent, pure solvent here, and the flow rate of the solvent is L prime 30 kilo mole per hour per

meter square. So, again make a note of this superscript L prime, because we are, we are writing this flow rate in terms of per meter square cross-sectional area. It is a pure solvent; so, x_2 equals x_2 equal to 0; it is given as 97 percent of sulphur dioxide has to be removed, to be removed, which means y_2 can be calculated as 0.00261. So, this is 97 percent that means 0.087 multiplied by 0.03, 97 percent of removal. So, remaining is 0.03 percent. So, we have y_2 , and then, we can write capital Y 2 very close 0.026. So, this is level two, this is level one, and the spent liquor gets in here at certain mole fractions x_1 and capital X 1.

Equilibrium is given this time as an expressions as y equals $2.5x$ plus $4.5x^2$. So, this is a equilibrium curve. We have to answer certain questions here. First, calculate minimum solvent requirement. So, this problem we have addressed in earlier lecture also. So, we calculate minimum solvent flow rate - that is one. What is the concentrations at the exit of the spent liquor? So, this is x_2 . What is the mole fractions here? x_1 actually. So, this will become, excuse me, this is your x_1 . So, this is a level 1. x_2 is 0, pure solvent. And, the third question is, calculate absorption factor A at the location where x is 0.02. So, where the mole fraction is 0.02, we say 0 here, and some values here, at the locations where the mole fraction is 0.02, calculate this absorption factor. And, the last question is, also calculate individual gas phase mass transfer coefficients. So, what is a small K_g equal to at the same locations where x equals 0.02? We have also been asked to calculate Δx Δy - the driving force for mass transfer, driving force for mass transfer.

Let us do one thing. Let us redefine this problem here. So, we have, let us calculate this; just calculate driving force for mass transfer based on this gas phase. And the given quantities are K_x or K_l as 1.2 kilo mole per meter square per second per Δx and K_y K_g as 0.15 kilo mole per meter square per second per Δy . And all of this, has the same location at x equal to 0.02. So, all we have done, let us start here, we have marked our coordinates y_1 , here we have x_2 , here we have y_2 , we know this equilibrium curve or we are supposed to do draw this graphically. So, let us draw this graphically. Let us do it graphically.

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We have capital X and capital Y. So, that is where we have been working, trying to plot, do the calculation based on solute free basis. So, if we have equilibrium curve given as small y equals 2.5 x plus 4.5 x square, we can write it as y over 1 plus y equals 2.5 capital X over 1 plus x plus 4.5 x over 1 plus x square.

So, if you recall in the last previous all lectures, we said that all the problems of absorptions can be done by graphically or one can solve analytically. So, even if you solve analytically, it is a good practice to draw the graph **and to** and mark the points, salient points, salient features at least qualitatively. So, after doing this, then you can take your decision whether you want to solve graphically or you want to solve analytically. Sometimes, it is easier to solve graphically; sometimes, it is easier to solve analytically; so, let us do that.

So this, we can draw this equilibrium curve. So, this is a equation, we have drawn the equilibrium curve here. Let us mark the point here. We have capital Y 2 as 0.00261 at x 2 equal to 0. So, we have marked this point. And y 1 is given as 0.087. So, the first question asked was - what is the minimum solvent flow requirement? That is easy to find out; it this shape of this curve is convex down, that means, we can draw this curve intersecting this equilibrium curve here. This will give us the concentrations of a spent **liquor** maximum.

So, this is the maximum, we have L_s by G_s . So, this will give you the highest concentration we can have in the spent liquor, corresponding to this minimum L_s by G_s flow rate. So, this X_{max} , from the graph if you will plot it this will turn out to be around 0.31. So, one can solve graphically, and if you want to solve these numbers analytically, all you have to do is, take this equations, operating line, intersects and solve together with this equilibrium curve. You can think that, you can see right here that the solving analytically may be a bit confusing, because equation is quadratic, one has to do some iteration here. But if we have plot it carefully on a graph, you should get this result immediately; the point where this L_s by G_s minimum curve intersects with the equilibrium that will give us X_{max} as 0.31.

So, from here, L_s by G_s , the slope, we can obtain L_s by G_s minimum; if you know this slope, I will leave this as an exercise, one can obtain L_s prime. So, note this here. So, far we have been used to plotting L_s by G_s , but L_s by G_s is same as L_s prime over G_s prime. So this is kilo mole per hour or per second; this would be kilo mole per hour per meter square. So, cross-sectional area of this column. So, we can write L_s by G_s as L_s prime over G_s prime. So, from here, we can calculate L_s prime as 24.85 kilo mole per hour per meter square. So, this is the minimum solvent flow requirement corresponding to this minimum slope. But given is L_s prime equals 30 kilo mole per hour per meter square. So, look at this difference here, L_s operating is approximately 1.2 times the L_s minimum or L_s prime minimum. So, most of the calculation in the earlier lectures we did it at 1.5, but that is alright. Here in this problem, the operating flow rate is 1.2 times the L_s prime minimum.

If you want to solve analytically, so, look at all we have to do is, we have to write down the expressions for operating line which is capital Y_1 minus capital Y_2 equals L_s prime x_1 minus x_2 . So, this would be our equation for operating line. And make a note here that we are using this superscript again, because this is per meter square. So, this will get cancelled either G_s or L_s or G_s prime and L_s prime.

Now, look at here, y_1 is given to us, y_2 is known, x_2 is known to us, which is 0 here. x_1 is not known to us and L_s 1 minimum is not known to us. So, all it means G_s prime is given to us, we are supposed to solve these equations 2 with equation 1 if you want solve analytically.

So, the solution is or the method is quite cumbersome. Of course, as an exercise you can try solving these equations together with this equation 1 to obtain the same results for L s minimum at 24.85. So here we are making this message here, that very often, it is very convenient to solve graphically. You draw it on a graph excel sheet or just take a graph paper, and you are careful in the drawing those, you know you have taken enough points for drawing this equilibrium curve. Then by taking this L s by G s minimum one can obtain immediately this X max 0.31 or the slope of this curve; so from there we can calculate L s minimum. So, very often it is **it is** possible to solve you know, minimum effort this graphically. But even if you want to solve analytically, it is a good idea to draw different points qualitatively.

So, let us get back to this problem. This is L s by G s minimum, and of course, we have running at operating curve L s prime by G s prime, both are given to us; the L s prime is 30 kilo mole per hour per meter square and G prime is given to us 10 kilo mole per hour per meter square. G s prime is given to us 9.2. So, from this if you can draw this line, this will give us the operating x 1, which will turn out to be 0.02588.

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$$G_1'(Y_1 - Y_2) = L_1'(X_1 - X_2)$$

$$\downarrow \quad \downarrow \quad \downarrow \quad \downarrow$$

$$0.02588 = X_1$$

$$0.02523 = X_1 \text{ (spontaneous)}$$

$$(2) \quad 'A' = \frac{L}{mG} = \frac{L_1'}{m G_1'} \quad \text{at } X = 0.02588$$

L_1' and G_1' will remain constant

$$m = \left(\frac{dY}{dX}\right) = 2.5 + 7X \Big|_{X=0.02588} = 2.68$$

$$\text{Op. Line: } G_1'(0.087 - Y) = L_1'(0.02588 - X)$$

$$Y = 0.069 \Rightarrow X = 0.02588 \quad (X = 0.02)$$

$$G_1' = G_1'(1 + Y) = 9.83 \quad L_1' = L_1'(1 + X) = 30.61 \Rightarrow A = 11.6$$

Again here, one can take this curve, and one can write these expressions, operating curve at G s prime y 1 minus y 2 equals L s prime x 1 minus x 2, G s prime is given to us, y 1 y 2 are known to us, L s prime we know the operating 30 kilo mole per hour per meter square, x 2 is 0. So, x 1 can be solved here to obtain same as what we have obtain

graphically as 0.02588. So, the spent liquor concentration is x_1 , and if you convert this into mole fractions, small mole fractions, **mole fractions**, based on for the solute and we have 0.02523 as a mole fraction of sulphur dioxide in the spent liquor. So, of course, for this part of the problem, one can solve analytically and one can solve graphically also; we will get the same results.

Now, let us try to answer the second question where it says, calculate A - absorption factor - which is nothing but L by $m G$. And that we can write as L' $m G'$. So, L' is known to us, G' is known to us. And we have been asked to calculate this, at a location, at x , small x , equal to 0.02. So, make a note here that L' will change along the column G' will also change with the column. L_s' and G_s' will remain the same, will remain constant. But L' and G' will change. So, the question is, calculate this quantity at x equal to 0.02.

So, first is the slope m ; m is nothing but dy by dx which you calculate, differentiate equations $2.5 + 9x$. Evaluate this at x equal to 0.02 or capital X equal to 0.0204 to obtain this 2.68. So, now, we have to get L and G , for this we require y ; what is a mole fraction corresponding to this 0.02? You make use of again operating line equations. We have $G_s' - 0.087 = y$. So, this is y_2 here. So, this is y_1 actually. So, capital $Y_1 - \text{capital } Y = L_s'$; similarly, we have $x_1 - 0.02588 =$, just now we have calculated 0.0204. So, we have this 0.0204. G_s' , L_s' is known to us, we get capital Y equals 0.0691. This will give us mole fractions 0.0647 corresponding to x equal to 0.02.

So, we can write as G' as $G_s' + \text{capital } Y$ to obtain 9.83 kilo mole per hour per meter square. Similarly, we can write L' as $L_s' + x$ to obtain 30.61, and then, one can calculate A equals 1.16. So, we have absorption factor, knowing slope of the curve 2.68, knowing L' which you have calculated 30.61, G' 9.83 at this location where we have mole fraction is 0.02 to obtain this absorption factor 1.16.

So, here also we can conclude, from this example, that absorption factor changes along the absorption column. Why? Because, even if we have the linear curve slope m may be constant; here, of course, it varies, but in those cases where the slope changes, it is possible that L' over G' or L over G will change along the length. Because liquid flow rate changes, gases flow rate changes, there is mass transfer, not necessary L

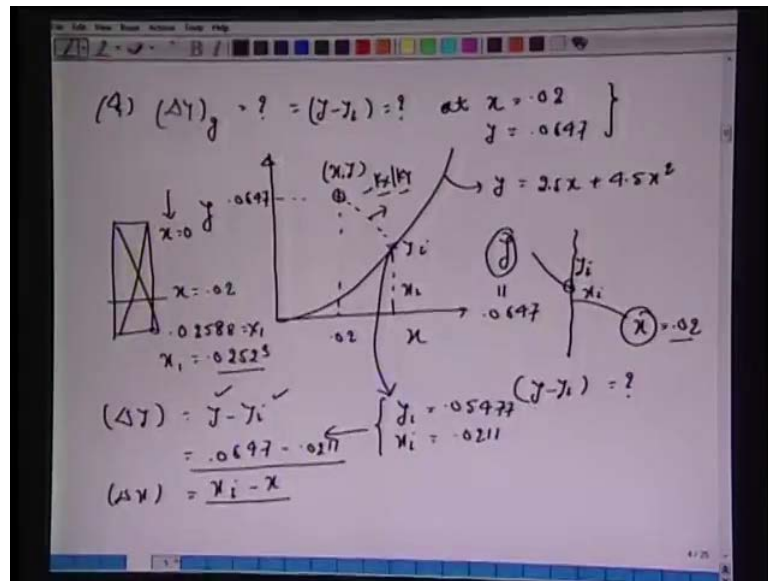
by G_s will remain the same. L_s by G_s will remain the same, because individually they remain constant along this absorption solute free basis.

So, in this example, the question was calculate this absorption factor L by m over G at the location where the mole fraction in the liquid phase is 0.02. So, we have to do this calculation, we have to find out what is y corresponding to small x , for that we wrote down the operating line equations and operating line equation connects the bulk phase concentration given x , what is y when the flow rates. So, from there we get a small y , we calculate the capital Y solute free basis, and then, we calculate L' and G' at that locations where we have this mole fraction equal to 0.02; slope of the curve, we know, the equilibrium curve we differentiate to get dy by dx and we substitute this number for small mole fraction. So, this part of things we can have done without graphically.

And the last part, the question is - calculate the gas film, **gas film** based driving force. So, that is your y minus y_i . Again, the driving force in the columns if you recall it changes, because mole fraction of y changes, y_i the interfacial concentrations, if y changes interfacial concentration will also change. In some cases is possible that the difference y minus y_i may remain the same, but nonetheless we have suppose to calculate this driving force based on the gas phase film at the location where the mole fraction is 0.02.

So, if you recall how we did it, again we can do graphically and also we can do it analytically. So, to do the graphically, one has to draw the slope of this time minus K_x minus K_y . So, let us do it graphically as well as analytically.

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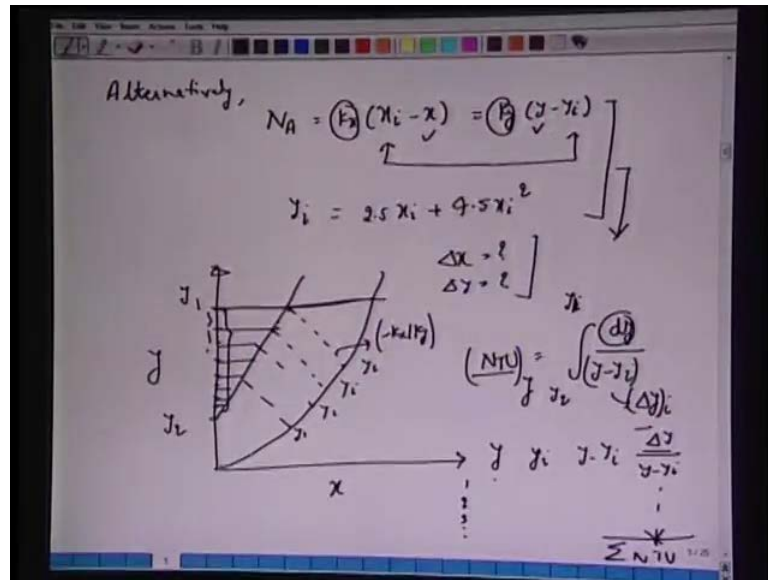
So, this is the last part of the questions where we have been asked to calculate Δy - driving force based on the gas film equal to what or $y - y_i$ calculate at the location where x was 0.02 and we calculated y corresponding to this x as 0.0647 in the previous part. So, if you draw this, want to do graphically or in otherwise it is good idea to draw graphically, we have this curve of y equals $2.5x + 4.5x^2$.

So, we draw this curve and the locations where the bulk phase concentration is given as 0.02 to 0.0647. So, this is the coordinate of x and y in the absorption column, x varies from liquid phase from x equal to 0 to be calculated the exit phase concentrations which was 0.02588. This was 0.02588 that was capital X_1 , but we calculated the small x_1 as 0.02523. So, the locations where x is 0.02, that is all we are trying find out. So, we have this interface, and we have this y_i and x_i , we have y and x . So, x is 0.02 and corresponding to this x equal to 0.02, y is given as **point** or calculated as 0.0647.

So, we are suppose to get y_i , so that we can calculate $y - y_i$. So, what we do or we do? We take the slope of this line, draw this curve with the slope minus k_x over k_y . So, the value of k_x and k_y is given to us. We take this curve on this graph, we take the slope it intersects here at y_i and at x_i . This coordinate if you do graphically it will turn out to be y_i equals 0.05477, x_i will turn out to be 0.0211. Based on this, we have the answer Δy equals $y - y_i$; y is known, y_i is equals 0.0647 minus 0.211.

Similarly, we can one could have also calculated driving force based on the liquid base x_i minus x . So, one can obtain these results from the graph and we must not forget that, alternatively, we can also solve by equations. So, writing down the equations instead of graphically, one can also calculate this x_i and y_i or A_x or y_i .

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So, alternatively, **so alternatively**, we can write down the equations. N_A equals $k_x(x_i - x)$ minus x equals $k_y(y - y_i)$. So, k_x is given to us, k_y is given to us; x is given to us, y_i is given to us; y_i and x y we are supposed to calculate; so, one equation; we have another equations, equilibrium curve y_i equals $2.5x_i$ plus $4.5x_i^2$. So, now, you can imagine, solving these two equations analytically, may be cumbersome, but you as an exercise, you must solve to get the same results for Δx and Δy as a driving force.

So, again here we have made a point that **that** certain class of problems, which you can solve you know very conveniently graphically. So, even if you are solving analytically it is not a bad idea to draw the curve, and then, you know, see what is given to us, what is not given to us, what are the quantities which can you know obtain graphically without doing any iterations mathematically.

So, that is the question we have answered; that is first another example on absorptions and the more important here also to note that number of transfer units, one can also calculate graphically as well as analytically.

So, number of transfer units, if you recall for a dilute solution where a very simple expression $\frac{dy}{y - y_i}$. So, again $y - y_i$ is the same quantity, which you have calculated here at location 0.02. So that $y - y_i$ is the driving force. All it means if you are suppose to integrate this quantity, dy by $y - y_i$ from y_1 to y_2 , we are supposed to draw several of this parallel lines of minus k_x and k_y . In other words, the way you will do mathematical integrations, you will divide your absorption columns into several small sections, preferably equal sections between y_1 and y_2 . And take those bulk phases, you know, (y_1, x_1) , (y_2, x_2) , (y_3, x_3) and draw these parallel lines.

So, you have the equilibrium operating line; you have the equilibrium curve; you can draw this operating line on the slope of minus k_x and k_y wherever it intersects that keeps you y_i and x_i , you can do the calculations for NTU, based on the gas phase dy by $y - y_i$ or dx by $x_i - x$ integral from x_2 to x_1 . You must get a number of transfer unit based in the gas phase, number of transfer based on the liquid phase multiplied by respective height of a transfer unit based on the gas phase or height of a transfer unit based on the liquid phase to obtain the **same** or height of the column.

So, just to sum up here; the same curve, since we are talking of driving force, let us again try to understand the meaning of this NTU. So, we have NTU as $\int_{y_1}^{y_2} \frac{dy}{y - y_i}$. So, this is what we have calculate this is a driving force of mass transfer based on this interface. So, we have $\frac{dy}{y - y_i}$. So, we have this equilibrium curve, we have the operating curve, we have the boundary here, y_1 , you have the boundary here, y_2 ; **you will takes** we will divide this y_1 to y_2 in several dy . So, you will take several of such sections, you know, may be 10 and obtain this. So, you have y_1, y_2, y_3, y_4 between these two domains and from each lines you will draw this parallel minus k_x minus k_y etcetera, the slope minus k_x over k_y , to obtain y_i corresponding to this y_1 , another y_i corresponding to this.

So, we have all $y_i(s)$ and then we can do this calculation for number of transfer units you will make a table of y, y_i here, then you will have **then you will have** $\frac{dy}{y - y_i}$ or $y - y_i$. You will have $\frac{dy}{y - y_i}$; $\frac{dy}{y - y_i}$ need not be the same. In another words, this can change here; it is a good practice to keep it uniformly between two domains y_1 and y_2 . Then you will make take several such points 1, 2, 3 etcetera, may be 10, and if you add all this, summation of this column to get you NTU - number of transfer unit based on this gas phase y .

So, this example also very similar to this; it is a graphically here, you draw a graph here, and draw this parallel curves, be careful with the **with the** drawing these lines, you have to extra careful. So, that your **y i** numbers which is very accurate.

So, this is the end of our lecture on absorptions. So, that is the first unit operations we took into this course. We listed some of the unit operations, which are covered in this course: absorption, distillation, extraction, adsorption and drying.

So, now we start **the** with the second part of this, second unit operation, which is distillations. So, now you recall in case of absorption, we gave an example of flue gas sulphur dioxide in air, ammonia in air, SO_2 in air, carbon dioxide in air and we bring a solvent, aqua space and then, we separate sulphur dioxide from atmosphere or ammonia from atmosphere into this solvent. So, at the end of the day, we have two phases, we start with the pure solvent liquid and we have A plus B - carrier gas and the impurities. And what we have done, we have transferred one of the components into the solvent. So, all we have done we have brought a contact two phases here. We do not give any energy. It is possible that certain absorption could be exothermic energy. So, some heat may involve and the process may be non isothermal, that also happens. But in most of the cases, we have nearly uniform temperature in the column or at least in the calculation which we have done, we have assume isothermal conditions. So, the mechanism for absorption is based on solubility. You have a gaseous mixture, you bring a solvent in contact, and then you remove it, you separate it.

Distillation is another unit operations, where if you ask to separate A from B, then we are not bring any third component. We bring now energy. So, starting with a liquid or aqua solutions of A and B, if you want to separate A from B, the mechanism here is relative volatility. A is more volatile than B or B is more volatile than A, which means at a constant temperature, at a given temperature, A and B they exert different vapour pressures, which is significantly different, in the sense that one can achieve desired separation there.

So, start with a liquid, give energy, vaporize. So, now, you have liquid vapor mixtures two phases - A plus B and A plus B. The only thing is the vapour phase will be rich in A and the liquid phase will be rich in B. So, take one stage, take to the second stage, again give an energy, again vaporize the new mixtures. So, you have cascades or trays in a

distillation column, where on the top, you have a stream of A plus B, but A is nearly pure. In other words, we can have a purity of 99.999 percent. Theoretically, of course, we can say that A in that mixture is on the top A is 100 percent pure and at the bottom the liquid is rich in B, lean A, and we can say that theoretically that B is 100 percent pure.

So, make a difference between absorption and distillations. Absorption does not involve energy; at least you are not giving any energy there. You are giving a third component. So, we have say desorption, just reverse of absorptions. We have aqueous mixture of ammonia dissolve in water, how do we remove? We bring a third component air; if we bring air, then ammonia gets transferred from the aqua phase to air phase. So, our water not becomes pure and pure, but look at the stream vapor phase, now water can also evaporate, vaporize to make the system of A plus B plus C.

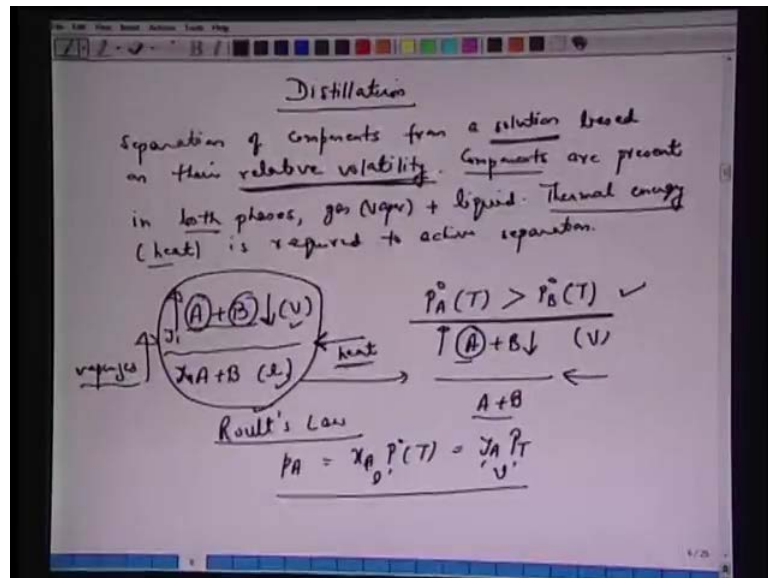
In case of distillation, we do not bring any third component. We have A plus B; we give energy - substantial amount of energy - to cause a separation depending upon the relative volatility of A and B or the difference between the vapor pressure of A and B. So, we achieve a separations, but now we have both liquid and vapor containing A plus B. Compare these two evaporations, we have saline solutions, you know sea water, water containing salt, and what do we do in evaporations? We do give energy, but when you give energy its only water, which gets vaporized, salt does not get. Unlike in distillations, where we have mixture of A plus B, and if you give energy, we have the vapor phase, which also contains A plus B. Slowly and slowly, of course, we make the vapour stream rich in one component and the liquid phase in other components.

So, distillations, well, compare to some extent with absorptions within the concept of height of it, you know STU, NTU or loading and flooding, some of the aspects in what we have covered in absorptions or the mathematical treatment we did for absorption, may be applied for distillation as well, concept of mass transfer coefficients etcetera. But distillation we will have a different treatment - different mathematical treatment - to find out the number of trays here.

Absorption mostly we did for continuous packed bed columns. And distillation we have a stage-wise, in practicing industrially, it is possible to have absorption in trays wise and we can also have a distillation in a packed bed column. But those are very, very few

cases and our discussion for this course, will be limited distillation in trays wise, stage wise and absorption which we did in a continuous packed bed column. So, before we start this mathematical here, let us summarize some of the main points for distillations.

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So, we have distillation. So, we say it is also a separation process, separation of components. So, we can have binary components for simplicity or we can have multi components. So, separation of components from a solution. Now, again when we say solutions our **feed** need not be a gas phase, need not be a liquid phase. For example, air 21 percent oxygen and 79 percent nitrogen. All we have to do in distillations, if you want to distill air, we have to liquefy air to the liquid phase, then we do distillations. So, our starting point may be a gaseous phase, but in distillation it has to be liquefied to start with the **feed** which could be a pure liquid or could be a mixture of liquid and vapour.

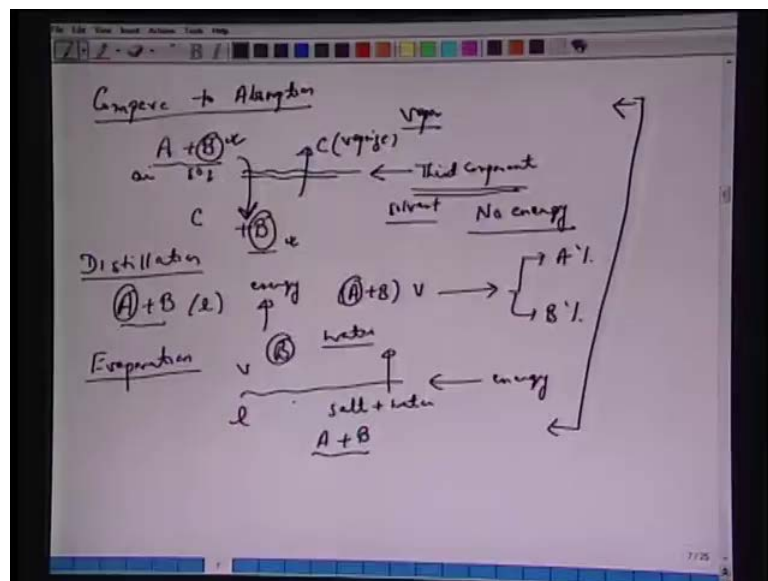
So, separation of components from a solution based on their relative volatility. So, this is the mechanism. Here, it is not a solubility, which we did in case of absorptions. More important here or also important to note here is, components are present in both phases, which is gas or actually vapour plus liquid. And another thing here is thermal energy or heat is required to achieve separation. So, the three things to note here: one mechanism here is relative volatility; second components are present in both phases; and third, we required this heat to cause the separations. So, if we have a start with A plus B in the liquid phase, we have to give energy - heat - to cause a separations we have A plus B in

the vapor phase. So, there is no third component; all we have component is here is heat which vaporizes this liquid. And when it vaporizes, if A is more volatile than B, that means the vapor pressure of A at any temperature is larger than the vapor pressure of B at the same temperature, now we achieve enrichment of this vapor phase with A and small quantities of B. So, this is the way are going to do it. We take this mixture of A plus B, give them heat - energy, make use of difference in the relative volatility or the vapor pressures, to achieve this separations from one level say y_1 or x_1 **two** in this phase, which is rich here may be in y_1 y_1 is much larger than x_1 .

Take this second products, go to the next stage, there again you have A plus B, now you starting with different mole fractions here, again give this heat here, again you cause the separations A plus B, A is again richer in this component, the vapor phase is now richer in A and linear in B. So, this is a stage wise process here, if you can still apply Roul't's law. So, Roul't's law is applicable to obtain this partial pressure of A as function of mole fractions and the vapour pressure, and also related to mole fraction in the gas phase, vapour phase and in the liquid phase.

So, these are the features of distillation here. Relative volatility, one separation is possible, but we have both A plus B in present in vapour and the liquid phase. One phase becomes richer in one component, which as a higher vapor pressure than the others and heat is required here.

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So, compare this to absorption. So, we have now A plus B, say air and SO₂. We brought in contact with a third component. So, this is third component, and here one has to be careful, this third component is solvent should have larger solubility for B, which we want to remove, but we have to bring this third component. No energy, we do not require any addition of energy. Although, they react, all this, although the absorption could be not as thermal or exothermic.

Now, when we have this B, A plus B in solvent C now. So, three components; A plus B binary components brought in contact with C, B gets transferred here. So, we have C plus B and it is there is a possibility of this C getting vaporized. So, what we achieve here, one - look at the difference sulphur dioxide is getting transferred into this. So, this component in this vapor phase may be leaner with sulphur dioxide. But, the solvent phase is not getting richer with B here. So, we have one stream where we have A, this A plus B which contains very small amount of B, but now we have brought this B transfer here by bringing in the third components.

In case of, distillations we have A plus B as a liquid phase, give energy, to bring A plus B as a vapor phase, no third components. But now, A will be richer than what we have in case of liquid phase, and slowly and slowly if you do this it is possible to do it in, obtain theoretically, A 100 percent pure A and 100 pure B. Unlike in absorptions only one stream can be pure, deprived of the sulphur dioxide, but another stream another phase is rich with B. So, making difference here in case of absorption and what we have in case of distillations. If you have evaporations, compare this to another unit operations, evaporation which you may have done in some other course mass transfer I, where we have the salt plus water. We give energy to vaporize; now you have water, salt does not get vaporized. So, we have A plus B, but only B gets transferred from this phase to the vapour phase liquid.

So, you should be able to see a qualitative difference between absorption, distillation, evaporation as you know different unit operations to achieve this purity. In all these three cases, we have separations; we want to separate A from B, but the method is different. In one case, it is extensive energy, you have to give extensive energy. So, the heat contents or the vapor phase is substantially different from the heat contents of the liquid phase. Or A in A plus B has a very larger different heat contents than A and A plus B, unlike in absorptions. In case by distillations, we can have 100 percent A and 100 percent B pure

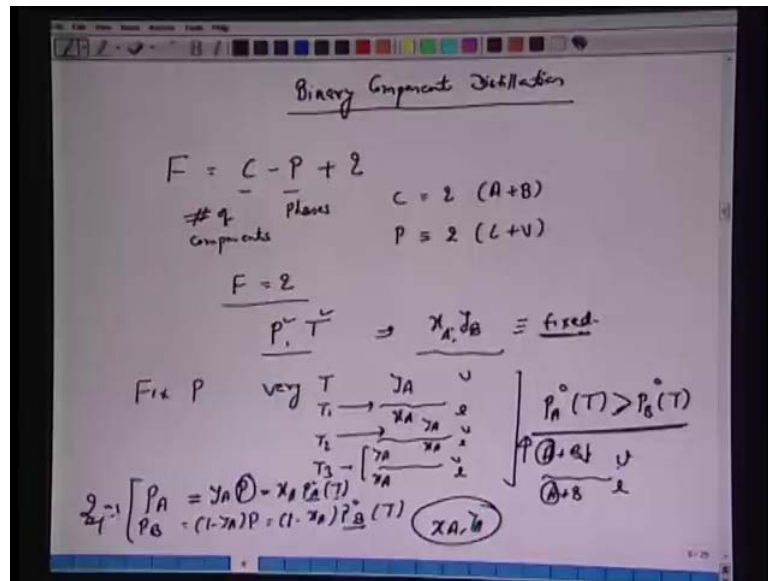
theoretically, 99.99 percent. But look at in case of absorptions, yes, flue gas we have removed, we have made air cleaner in sulphur dioxide. But the liquid phase is highly contaminated with the sulphur dioxide. We cannot take this dump, this is spent liquors, one has to bring, you know, take this stream to the desorption, we have done taken that example earlier also, to again clean this spent liquor.

So, the application is different, that is one; the mechanism is different, in one case is solubility, in one case, this is your relative volatility. There has to be substantial difference in the vapour pressures to achieve this significant amount of distillation or separations.

In one case, this is choice of solvent, I have to bring a good solvent, which can remove S₂S or SO₂. Here, there is no third component; it is energy; it is a very extensive energy process; that is why distillation you will see, when we come to the stage of designing this distillation column or determine this number of trays will be two approaches: one would be enthalpy-based approach; one would be species balance or mass balance approach. Because, there is a difference in the enthalpy or heat contents of the products of the mixture from stage to stage. So, by taking, you know, keeping track of exchange in enthalpy one can also decide, one can also evaluate or determine the number of trays.

So, **before we...** So, in the next topic or in the next sub topic for distillation would be we must understand vapor liquid equilibrium. Because, this is what we are going to have start with the liquid, two components were simplicity, vaporize you bring another phase, create another phase of vapour, which would be in equilibrium with the liquid. So, A plus B in the vapor in equilibrium with A plus B in the liquid phase. So, what is the equilibrium, we decide of course, we can be rely on Roul't's law. Remember, Roul't's law we also applied in finding the solubility for assuming it is an ideal solutions. So, Roul't's law can also be applied for this liquid vapour equilibrium for distillations and also for liquid vapor or gas liquid solubility. So, let us we will start with binary component distillations.

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So, this is for the simplicity, I will focus mostly on binary component distillations. And, we will spend small, **small** amount of time on multi component distillations. First thing is of course, degree of freedom, which we know from your previous some course on thermodynamics, degree of freedom can be written as C minus B plus 2, components - number of the components - number of phases; number of components, number of phases.

So, in our case, we have C 2, two components A and B, phase we have two - liquid and vapor - which means degree of freedom is 2. All it means, if you fix pressure and temperature, then x and y mole fraction of A and mole fraction of B or mole fraction of A in gas phase or vapor phase and the liquid phase they are fixed, which means fix pressure vary T - T 1, T 2, T 3 - we have the equilibriums between the two phase vapour-liquid, vapour-liquid, vapour-liquid. But the mole fractions here, x, x A and y A, y A, y A x A, y A x A they are all fixed for different temperatures, because degree of freedom here is 2. Though, here the requirement is that vapour pressure of A at any temperature should be larger than the other components.

So, this is the in a bottom line for the distillation, there should be significant difference in the vapor phase; quantitatively of course, we will do the calculation in the coming classes. But the idea here is that one can apply Roul't's law partial pressure at equilibrium between the two phases - vapor and the liquid A plus B here, and A plus B here; this

vapor phase is rich in A and lean in B. Relative to this, it is richer here and lean in P. How quantitatively we can calculate as partial pressure of A as $y_A P$ equals $x_A P_A^0$ or P_B equals $1 - y_A$ which is y_B as total pressure equal to $1 - x_A$ which is x_B .

So, fix this P and T. Fix the pressure and temperature, we know the vapor pressures of A and B, we have two unknowns x_A and y_A to calculate from these two equations. So, that is a meaning of degree of freedom. Once we fix the pressure and temperature, mole fraction of A and B they are fixed in the both of phases. Take to the second tray, where the temperature is different, you achieve different degree of separations.

So, for every pressure fix pressure generally discussion column we will **done add of** expressions. Fix P, vary T_1, T_2, T_3 ; for every T_1 there is $x_{A1}, y_{A1}, x_{A2}, y_{A2}$. This is the way y A or component A will become richer in one component. So, vapor will become richer in A y_1, y_2, y_3 and the liquid will become richer in B, you know, from x_{B1}, x_{B2}, x_{B3} etcetera. So, that is your distillations order separation here.

In the next class we will draw this curve what do you call T x, y diagram - phase diagram. So, we will do the same calculations, we should be able to this phase diagram, very similar to what we did in case of absorption and we have this equilibrium curve or the solubility curve. So, you have very similar approach, first is the thermodynamics - thermodynamics will tell us, given one phase composition, what is the composition in the second phase; there we have the solubility, here we make use of this Raoult's law to obtain T x y diagram or y x diagram. From there we have the equilibrium curve, in case of absorption, we wrote down the operating balance, operating line equations, in case of distillation also we will write down this operating line curve.

Here, we have luxury of writing down these operating line equations either in terms of species balance or making use of change in the enthalpy. So, there are two different approaches, because here there is significant change in the temperature from $T_1, 2, T_3$ etcetera. So, given T_1 heat contents are different for the liquid phase and for the vapor phase. So, with that, you know, by making use of this property or this feature that enthalpy changes from tray to tray, stage to stage, one can work exclusively on the enthalpy balance. So, we have two types operating curves, or two types of approaches:

one is based on the species balance, one is based on here or material balance; one is based on your enthalpy balance. So, in the next class we will come back to this.