Mass Transfer II

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Module No. # 01

Lecture No. # 08

In today's lecture, we take an example of what we have done in case of material balance for stage wise processes. We will solve this example, by both graphically as well as you know writing down the equations.

So, essentially we will take a very simple example, we will have one stage two streams getting in and with certain aspects of the feed. And what concentration we want to bring down the levels from one to another and see how much is the solvent requirement and then, we will extend the same example for multi stages. So, we will have three stages, and we will answer the same question, how much is the solvent requirement to bring down the level of Raffinate phase from one level to another phase.

Our idea is to understand what we have learnt, you know when we wrote down the expressions for material balance, how we can solve, how we can address the same problem by graphically by graphs.

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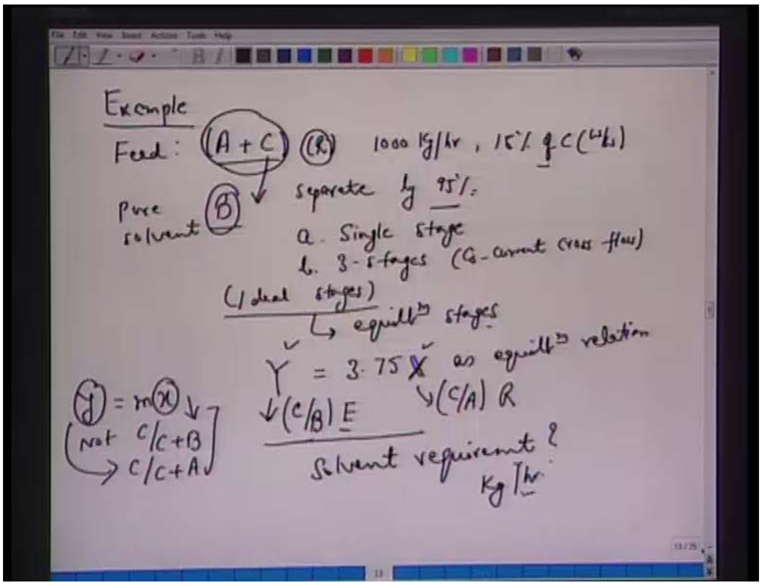

Example

Feed : (A + C) (R) 1000 Kg/hr , 15% of C (wts)

Pure solvent (B)

separate by 95%

a. Single stage

b. 3-stages (Co-current cross flow)

(Ideal stages)

↳ equilib^m stages

$Y = 3.75 X$ as equilib^m relation

$Y \downarrow (C/B)\ E \qquad X \downarrow (C/A)\ R$

Solvent requirement ? Kg/hr

$y = m x$

(not $C/C+B$ → $C/C+A$)

So, let us take this example, again we will focus on binary components, so let us say we have a fluid mixture, a mixture of A plus C. And we call this R phase raffinace raffinate phase, and we have a solvent we call it B and we want to remove the C, this component from one level say, this A plus C let us put some flow rate here.

So, the rate is 1000 kg per 1000 kg per hour. And it contains 15 percent of C weight by weight bases so, W by W. And we have been asked to separate C using this pure solvent B; so, B is a pure solvent. And we have to separate C say by 95 percent, which means we remove C in this component A plus C in this mixed feed A plus C, if you call it feed or phase by 95 percent using this solvent B. And there are two cases here, A we have single stage and B we have 3 stages.

These 3 stages are co-current cross flow all right, what we did in the very beginning of this section of the course, and we also assume ideal stages. So, all the stages are ideal and if you recall we said ideal stages means, these are equilibrium stages.

So, talking of equilibrium, we have been given that Y equals 3.75 X, as equilibrium relationship. And very important to note that this Y it reflects the concentrations of solute in solvent, so this is actually C by B solute free basis, so we are using this X. So, this X is C by A in the feed or R phase, so this is your R phase and if you recall earlier nomenclature this is your E phase. So, two streams A plus C R is brought in contact with B and equilibrium is given by Y equal's 3.75 X.

Note: This is not y equals m X or a small y n x this mole fractions. This is solute free basis this is C by B not, C by C plus B or C by C plus A. Here we use this X and Y etcetera. So, this is all solid free basis and we have we have already seen, if we use the capital Y and capital X, we have operating curves which are linear.

So, let us go back again, 1000 kg per hour of feed contains 50 percent of C, we have been asked to remove or reduce by 95 percent. And the question is how much is the solvent requirement, solvent requirement in both cases; so, how much is kg per hour etcetera is required. So, we draw the schematic here example one.

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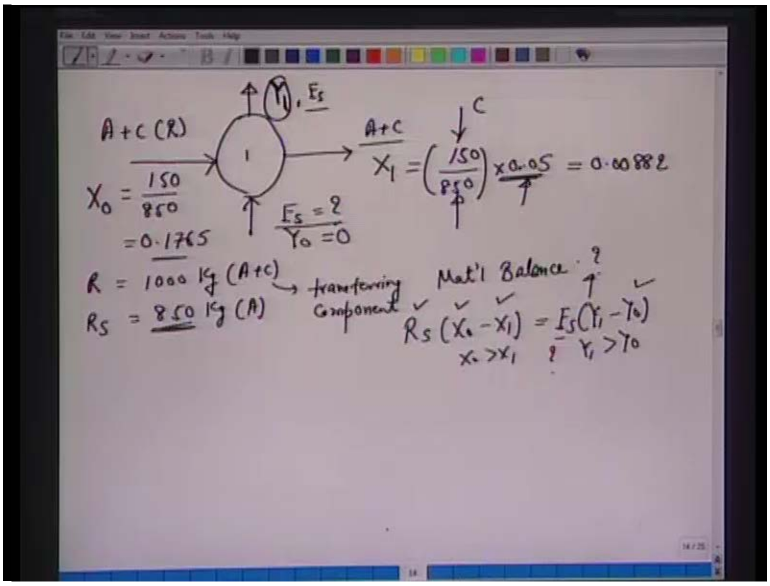

$X_0 = \frac{150}{850}$

$= 0.1765$

$X_1 = \left(\frac{150}{850}\right) \times 0.05 = 0.00882$

$R = 1000$ kg $(A+C) \rightarrow$ transferring component

$R_S = 850$ kg (A)

Mat'l Balance ?

$R_S(X_0 - X_1) = E_S(Y_1 - Y_0)$

$X_0 > X_1$? $Y_1 > Y_0$

We have this stage 1 first example. This feed consisting of A plus C, R phase is brought here, it has mole fractions, so X 0 is the fresh feed X 0. And since a feed contains 15 percent of A and the solute free basis mole fractions should be 150 divided by 850 850 or 15 by 85. This is your 0.17650, so this is a mole fractions solute free basis. We have R given as 1000 kg, so this would be A plus C, but we are working on solute free basis so, R S is 850 kg in other words this is a solvent 850 kg. So, this is your only A, C is a transferring component transferring component.

We bring in this contact with pure solvent E S that is the question what is E S? It is a phase fluid, pure, so Y 0 is 0. After treatment of this A plus C we have the treated fluid A plus C, now the mole fraction is X 1 and what is X 1? We were told that component C transferring component, now it reduces by 95 percent which means, if we have 150 if you starting with 850. So, X 1 would be 150 by 850 into 0.05 so, 95 percent of C has been removed, so we are using this solute free basis 850, it is a solvent R S and we have 150 of in the beginning here C, so we have removed 95 percent; so that means, 5 percent is left so, we have 0.05 percent and this number is 0.00882. And this stream now we have another stream here which has mole fractions Y 1 and this is your E s.

So, E s will remain the same because we said it is a solute free basis and Y 1 is unknown here, how much is a mole fraction concentrations here in the in the exit phase here. Now, of course, we can write a material balance all right, which is a very simple example we can write a material balance so, R S the feed which enters here X 0 minus X 1. So, this what is removed C, and it is gained in the second phase E s, Y 1 minus Y 0. So, note here X 1 is greater than X 1 and Y 1 is Y 0, because this phase picks up you know transferring component or diffusing component C here.

So, of course, a very simple problem everything is given here, R S is known, X 0 is given, X 1 is given, Y 0 is 0, and we have E S which is the question is how much amount of E S is required. So, this E S is unknown and Y 1 which is the mole fraction of the exit concentration is also unknown here. So, what we have done here is simple material balance in equal to out all right. So, in equal to out we make a species balance or material balance species balance for this diffusing component C here. We assume that A or B they do not transfer from one stream to another stream and they are brought into this stages here cascades.

So, now we have two unknowns all right Y 1 and E s, what is the mole fraction of the solvent solvent phase or E phase at the exit of this stage and how much is a solvent requirement?.

So, we are looking for one more equations. And now here comes the thermodynamics all right, if you recall the question, we said that these are ideal stages, all it means the 2 streams when they are brought in contact they are well mixed; they spend infinite amount of time theoretically or we say that they spend good amount of time, so that when they make an exit they are in equilibrium.

SO, which means Y and X at the exit, they would be related by these equilibrium relations which we wrote earlier Y equal to 3.75 x, so we have one more equation here Y equals 3.75 X, and Y equals 3.75 X its applicable for the exit Y 1 and X 1. So, we know Y 1 and we can write as X 1, X 1 is known to us 0.00882. If we substitute here, we get Y 1 which will be equal to 0.0331. Now, we know Y 1 and we can substitute here in the previous species balance to obtain the amount of E S very simple algebraic to obtain 4306 kg per hour. So, this is all kg per hour kg per hour here. So, it was a very simple problem 2 streams brought in contact they spend good amount of time there, so that the exit concentration are in equilibriums and we have been asked to determine the solvent requirement.

We note down this species balance whatever is transferred from E phase or from from R phase and goes into this E phase refined to extract phase all right. And then we write down the expressions we apply the equilibrium, independent equations for the exit concentrations Y 1 and X 1. Then, we have two unknown two equations we have solved. So, very simple but, more important here is let us see, what is our understanding graphically the graph, by graphically also one can solve.

And then we can mark those points equilibrium points, operating points what we have done earlier operating line etcetera that gives us a better understanding of the physical problems. Because the same concept same approach you would like to apply, you would like to extend when we have multi stages. Theoretically you can solve graphically or you can solve writing down the equations algebraic equations for a species balance for equilibrium equilibrium curves how many unknowns we have, how many variables are there and then you can solve it.

So, it is up to you how do you solve it right, in some cases it is better to work graphically to get the faster answer or for the physical understanding. Some times when the graphically we are unable to obtain, then we solve mathematically graphically algebraic writing down the algebraic equations. Very often in some cases if the problem becomes more complicated one has to resort to the programming, Fortran, C etcetera all right. And it is up to your choice depends upon the type of the problems. So, let us try to understand the same problem graphically.

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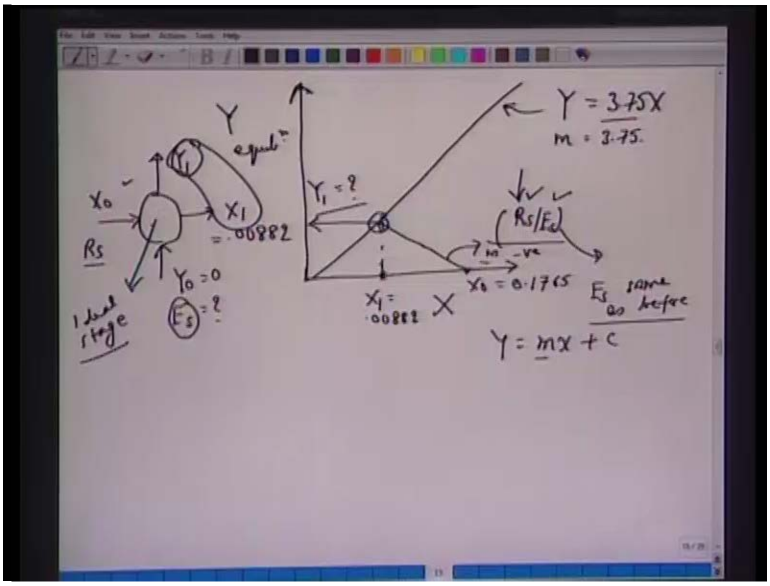

So, what we have Y and X and capital Y andcapital X all right. And the equilibrium curve was given to us Y equals 3.75 X all we do we plot this. So, now the equilibrium curve is this Y equals 3.75 X, where 3.75 is the slope of this curve. So, we can plot graphically. Let us mark down the points go back to this stage again, we have two streams getting end here Y 0 pure solvent is 0; and this is X 0 which is given to us. So, 1 0 0 you can mark it here, so this is X 0 and Y 0 is 0 here, so this number X 0 we know 0.1765, so that is a mole fraction solute free basis in the feed.

Exit we do not know this Y 1 we know this X 1 and X 1 we said its 0.00882. So, we can take 0.00882 all right so, let us see this is X 1 is 0.00882, so we know this point of course, we do not know Y 1 or the two ways are same you know result you will get. We know the flow rate here R S, we do not know this flow rate E S. If you know E S we can obtain Y 1, if you know Y 1 we can obtain this E S. But, now we know that Y 1 and these two streams they are in equilibrium, because we assume it is in ideal stage.

So, two streams which are leaving they are in equilibrium, which means if you know X 1, we can mark this we know immediately this Y 1, which we did earlier also, so we can take a pencil or graph a scale and you can obtain this Y1. If we connect Y 1 and X 0, we will get a slope here and the slope is nothing but, if you recall this is R S over E S all right. So, graphically it is sometime is easier to solve, if you take X 1 you know the equilibrium curve you mark this point connect this we have R S by E S. Once we know the slope R S is known we obtain E S same as before. So, I leave it to you as an exercise to check you obtain the values of E S similar to what we obtain by writing down and solving these material balance equations.

So, it is a very simple example the more important to realize that Y 1 and X 1 they are in equilibrium here. If you know X 1 you can mark E 1, suppose the same problem says that we know the amount of R S and we know the amount of E S. Graphically all you will do you will take the slope, it is a cross current you are adding it here write down the material balance you will get this negative slope here with negative.

If you write down the equations, as y equal to m x plus c you should, convince yourself that you are getting a negative slope; you mark the slope extend this still the equilibriums you will obtain Y 1, to obtain the mole fraction of exit concentrations of this E S phase of the solvent phase. So, again it does not matter graphically or algebra algebra algebraic right now, the algebraic equations right more important is trying to understand and mark what is happening in these stages here.

Now, let us get to the second stage second second part of the problem, where it says if you have taken the 3 stages. So now, we have one stage, two exit, two entering streams, two exit streams, We bring in contact with the second stage, and the second as stage again we had a fresh feed; again you treat it ideal stages two exit streams are in equilibrium, take this treated stream from the second stage bring it to the second third stage and there again you bring in contact with the fresh feeds. So, how much is now the solvent requirement R s 1, R s 2, R s 3. If it is assume that, we have equal solved flow rates so, how much is your 3 R s in compression to single stage which we solved just now.

So, the idea is still the same our feed is, A plus C here and we want to reduce the 95 percent of C in the A plus C streams by using three stages instead of one stage. And we will see how much is the difference is the solvent flow requirement, again one can solve graphically and one can solve writing down the equations. So, let us write let us draw the schematizing and see how we can solve the same problem by two methods.

So, here we have now three stages 1 2 and we have 3 so, in this is Y 0 X 0 so, we have Y 0 and we have this X 0. Now, we have stage 1 this becomes X 1, this is stage 2 this becomes X 2 and we have 3 this becomes X 3 and every time in all the stages we bring the fresh solvent. So, all these Y 0 same equal to 0 and we assuming, we have the same flow rates which is E s E s and E s. So, we have now Y 1, we have Y 2 and we have Y 3 and before we solve it is given that all three stages are ideal stages, which means Y 1 X 1 are in equilibrium, Y 2 X 2 are in equilibrium, Y 3 X 3 are in equilibriums. X 0 is given to us same as before 0.1765. And X 3 the stage from stage number 3, stream which is comes out from stage 3 this concentration is also given 0.00882, so these 2 are the same as before (Refer Slide Time: 18:18).

Flow rate R S same as before 850 kg. So, this is also given, this is given, this is given. Y 1, Y 2, Y 3 there are not unknown, E S, E S, E S are also unknown, Y 0 is 0 and we have been asked to solve determine the solvent flow requirement. E S plus E S plus E S or 3 E S equal to 1. And compare to the previous values which we obtain as 400 4306 kg per hour, so that is the problem, one can write down the material balance or species balance for all three stages, so let us write down the same balance which we wrote right.

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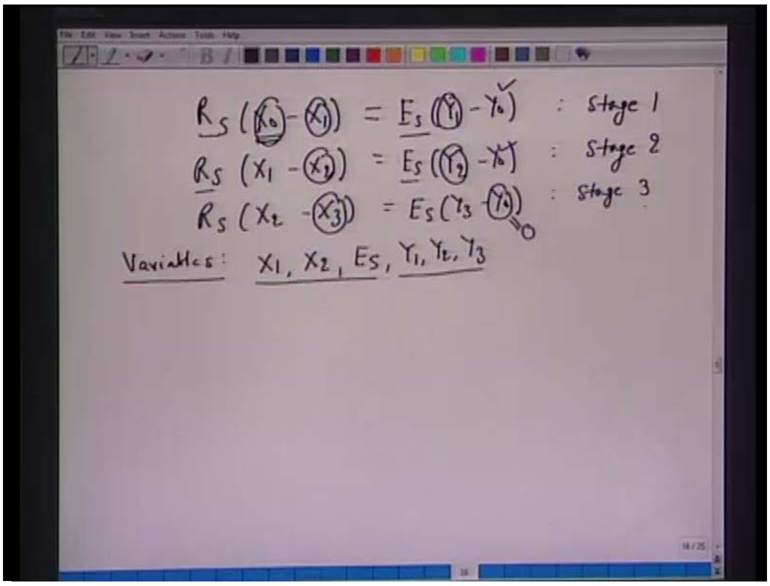

$R_s(X_0 - X_1) = E_s(Y_1 - Y_0)$: Stage 1

$R_s(X_1 - X_2) = E_s(Y_2 - Y_1)$: Stage 2

$R_s(X_2 - X_3) = E_s(Y_3 - \underset{=0}{Y_0})$: Stage 3

Variables: $X_1, X_2, E_s, Y_1, Y_2, Y_3$

So, what enters from the first stage is R s R s X 0 - X 1, this will be same as if you write down the second equations, which we had for the second stream which is E s Y 1 minus Y 0, so that is a stage 1. We can write down the same for stage 2 R S will not change, this is solute free basis solvent so, solvent flow rate will remains the same. This will be R S now, this would be X 1 minus X 2, so this is second stage. This will equal E s, we are assuming E S 1 is same as E S 2, so we do not have another subscript here, so it is E S and now, we have Y 2 minus Y 0 this is stage 2.

Similarly, we write the equation of a stage 3, as R S X 2 minus X 3 equals E S Y 3 minus Y 0 so, it is stage 3. And now we should identify, how many variables we have, which we are supposed to determine or unknown. Look at this, all we know is only X 0 and X 3, we do not know X 1, we do not know X 2, we do not know the solvent flow rates E S. We do not know Y 1, Y 2, Y 3, all we know we have Y 0 pure solvent entering every stage which is at pure 0 concentrations. So, we have 3 unknowns and we have 3 equations.

So, we require 3 more equations, so six unknowns and 3 equations and then if you recall, we have those 3 equations assuming all these stages are ideal. When they are ideal, the exit concentration there are in exit streams they are in equilibriums. So, Y 1 is equilibrium with the X 1 or Y 1 and X 1 they are decided, they are governed or they are related by this equilibrium curve, similarly, Y 2 X 2 and Y 3 X 3. So, we have actually three more equations, assuming these are all ideal stages.

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So, if they are ideal now we have Y 1 equals 3.75 X 1, Y 2 equals 3.75 X 2 and Y 3 equals 3.75 X 3.

Now, we can say that the six six unknowns and six equations six unknowns and six equations right. Of course, now the problem is well defined but, you must understand that if you substitute Y1 in terms of X 1, Y 2 in terms of X 2, Y 3 in terms of X 3; and then you try to solve solve this as an exercise you will see that, this is non-linear here right. You would not be able to solve you know directly, you will have to require iterations if you again try to substitute X 1 in terms of X 2 you will see you will get an quadratic equations.

Now, of course, the problem is well defined. We have 6 unknowns 6 equations this can be solved. But, the more idea more important here to notice that, we should also be able to solve graphically and see where is this linearity or non-linearity-best is here. The operating lines are linear, equilibrium curves are linear. And we know the 2 concentrations X 0 and X 3 all we know that leaving streams they are in equilibrium. We should be able to mark these lines on the graph, on the equilibrium curves, operating curves and see how we can solve it. That also improves our understanding of the problems which we have here, let us solve the same example by graphically.

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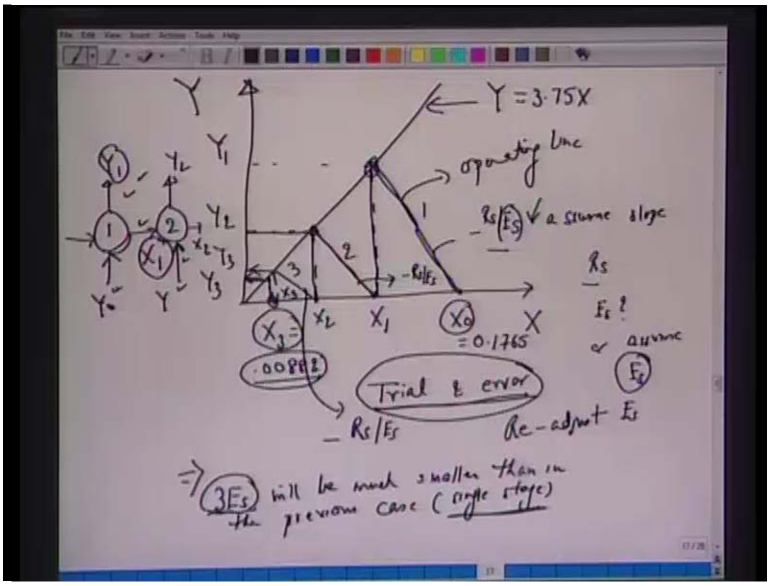

⇒ $3E_s$ will be much smaller than in the previous case (single stage)

So, now we have this equilibrium curve here, Y and we have X and this is our equilibrium curve, Y equals 3.75 X. Now, this is given to us X 0 which we said this equals 0.1765. Let us start from here so, this is X 0, we know R S right,, but we do not know E s, E s is not known to us, that means, we cannot draw this operating line, which has a slope of minus R s over E s. And the stage streams which two streams which we leave the stage 1, this Y 1 and X 1 we know they are in equilibrium; but, we do not know Y 1 nor we know X 1, so this point is also not known to us.

So, this would be if we know this point you can mark this would have been Y 1 and this would have been X 1. So, we do not know this E s here all right, so we do not know the slope nor we know Y 1 or nor we know X 1 these are the intermediate points. All we know the exit; finally, X 3 is here which we said X 3 equals 0.00882. We have been asked to reduce the concentration from mole fraction from X 0 to X 3 but, we do not know the flow rate E s nor we know Y 3.

So, all it means one has to make this iteration it is a trial and error trial and error. See we are experiencing the similar type of problems, what we faced earlier when we tried to solve mathematically. All it means we will assume one has to assume some slope here, assume slope or assume E s, which we have been asked to find out. Take the slope we get back to we get this concentration X 1. Now, the second stage again we have brought we are bringing this stream in phase contact with this fluid which is Y 0 Y 0 given to us 0 concentrations.

Now, if the amount is same here and here that means, we will get the same slope. So, assuming some values of E s, we draw the slope we get Y 1 we know Y 1 these 2 streams are in equilibriums, Y 1 and X 1 they are in equilibriums, so we can mark this point X 1. Again we can take the slope here, note that this line will be now parallel to this, because the flow rate of the solvent in the stage 2 is same as before. So, this slope will also be minus R s by E s. So, now we reach here, this point is coordinate would be Y 2 stage 2 and this is Y 2 stream and this would be X 2 which is here. So, we get this point here.

Now, we start third stage and we draw the same parallel lines with the same slope minus R s over E s. To obtain Y 3 and X 3, all mean it means if you are marked this 0.00882 we have not reach the same point, that is why we said it is a trial and error, one will have to readjust the slope here or we will have to readjust readjust the solvent flow requirement to reach one through 1 2 3 stages this X 3 what we want here right. Or alternatively one could have done this way also assuming X 3 now we know Y 3, we could have gone backward and to calculate this E s, to obtain this X 0 point here.

Either way this will work. But, more important to note here is that it is a trial and error problems, which you will encounter whether you solve graphically or you solve by racking down this equations. There also you will have the same encounter problem you will have to assume values of X X E s etcetera to solve those three equations all right.

The more and also to important note that, these points we have been able to marked this is operating line operating line, this is the equilibrium lines. We realize that two exit streams are in equilibrium, so Y 1 X 1, Y 2 X 2 and Y 3 X 3 they are on the equilibrium curves coordinates are on this equilibrium curves. And if you do this, one can obtain and to show that the amount of E s, I leave this as an exercise, that amount of E s in this case will be much smaller will be much smaller than in the previous case, which is single stage.

Actually the total amount of so 3 times E s because we are assuming that all 3 stages they have the same flow rates. Here the amount of solvent requires will much smaller than we have been in case of single stage here. I leave this as a as an exercise to solve graphically as well as graphically as well as you know by mathematically writing down the equations.

So, we have taken this example we took this example very simple example; the idea was to make a simple material balance, species balance or write down the equilibrium curve see how many unknowns we have, how many equations we have right. So, that the problem is well defined simultaneously also try to solve graphically or at least mark those points that this is entrance stream, this is the exit streams, what is the Raffinate concentrations, what is your extract concentrations, leaving stage 1, stage 2, stage 3. If the 2 stages are in equilibrium, the stages are ideal then the leaving streams will be in equilibriums and those points will be the equilibrium curves.

So, although this example was very simple for one stage or three stages. The example the idea of this example is your own understanding physical understanding of this mass balance or this equilibrium curve right. Now, we take one unit operations one by one. So, if you recall in our first lecture, we said that they are for unit operations which we are going to discuss very rigorously. One is absorption, distillation, extraction, adsorption and the drawing, so these are the 5 unit operations listed for this course mass transfer to here.

So, we take this absorption a first unit operation. So, now, when we say absorptions essentially, we have a gas phase gas phase is brought in contact with this liquid phase. So, let us take an industrial example; we have a power plants which emits sulphur dioxide or carbon dioxide certain pollutants into atmosphere and e p a agency like e p a all right environmental agencies, they say that the emissions cannot be cannot exceed certain level.

In other words sulfur dioxide in this flue gas from the power plant cannot exceed let us say 0.1 percent or 1000 P P M right. So, all it means before we emit or before we exit this gas this has to be treated by water or by certain solvent appropriate solvents, so that is absorption a gas phase brought in contact with a solvent liquid phase, so two phases and for simplicity we assume we have a binary phase.

So, air and sulplur dioxide, so air is one fluid of course, it contains oxygen nitrogen, but we have one fluid air and sulphur dioxides two components; and it is brought in contact with water which may be fresh pure water. But, when sulfur dioxide it absorbed into it water does not evaporate for simplicity all right.

So, this would be the most simple example of absorption. We have been given a continuous packed bed column. We talked about two different ways by which two streams can be brought in contact. Generally we have absorption column which is a continuous packed bed. So, we do not have trays or cascades, write the example which we took or in just now; it was a stage wise cascades, so generally applicable in distillation column or applicable in extraction.

So now, we have a continuous packed bed in which gaseous phase air is brought in contact with water. And we will see how do we go about it, which is how we can make a material balance, species balance and we write down draw the equilibrium curves, operating curves, how much is a stage of the height of the column, how much is the diameter, what is the diameter of this column. So, these are the process design or process variables which we are in (()).

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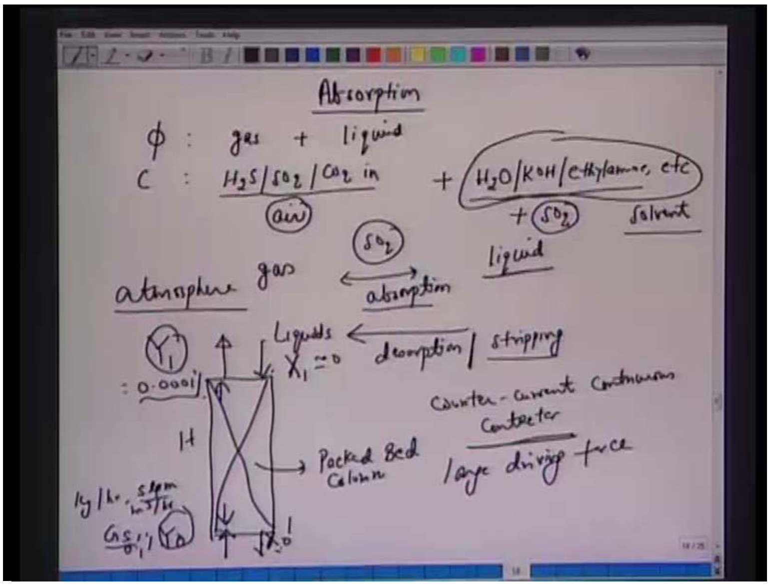

Absorption

ϕ : gas + liquid

C : $H_2S/SO_2/CO_2$ in (air) + H_2O/KOH/ethylamine, etc + SO_2 Solvent

atmosphere gas $\xleftrightarrow{SO_2}$ absorption liquid

Liquids $\xleftarrow{}$ desorption / stripping

Counter-current Continuous Contactor

large driving force

So, we begin the first unit operation, absorption so, we have two phases gas plus liquid. And we have two components so, we have say H 2 S example or sulphur dioxide or say carbon dioxide in air, so we have two components one component is air, and the other component is let say sulphur dioxide. It is brought in contact with the liquid, so we have some solvent H 2 O or say K o H or say we have some ethylamine etcetera. So, this is one component and when sulphur dioxide is at absorption we have this sulfur dioxide. So, this is the component sulfur dioxide which diffuses from air or gas phase to this liquid phase, so this is absorption. And you can imagine that, if this liquid is saturated with the gas, we can also have desorption so, it is a reversible process. Absorption slash desorption, desorption is also known as stripping.

So, the principle of absorption or desorption or stripping is similar. So, this is what we are trying to address here, just draw a column and we call it packed bed column (Refer Slide Time: 36:45). So, we will discuss, the configuration of different type of packing; all we are seeing right now it is a packed bed column. This air containing sulfur dioxide is brought from one end, so we can again mark some concentration here mole fraction let us say this is Y 0, so for the gas phase we use, so Y 0 flow rate is given say G S.

So, again solute free basis sulfur dioxide free basis flow rate is a given kg per hour or standard deter per minute or we can have certain cubic meter per hour etcetera. Flow rate is given say 1 percent or 0.1 percent of sulphur dioxide in atmosphere; we have been asked to reduce this concentration to Y 1, say 0.0001 percent before, this goes into atmosphere. To do this we have been given a fluid one of this fluids so, it is a liquid one of the liquids as a solvent so, this is solvent; so, this liquid is given and we have been asked to reduce this concentration from Y 0 to Y 1.

So, this liquid and gas the weight is shown now it is in the countercurrent countercurrent continuous contactor. We can also have co-current and this is the most common and most advantageous, we discuss earlier that countercurrent continuous contactor has large driving force larger than co-current as a consequence the height of the column is smaller in this case.

So, again we will come back to those details later. Let us say that we have this packed bed column so, here we have some kind of packing we will discuss this also later. So, this 2 streams are essentially brought in contact countercurrent direction opposite directions. And then and this gas is treated and then it makes an exit after the concentration is so much reduced and the liquid concentration changes a pure solvent if X 0 is approximately 0 or X 1 right; so for the end here Y 1 this is X 1 and here this is Y

0, so we have this X 0 here. Now, let us start with before, we get into the detail design or write down the operating balance, if you recall we have to establish the equilibrium.

So, we are talking of absorption from gas phase certain species transfer into the liquid phase sulfur dioxide from air into water. So, there has to be an equilibrium curve, in other words given pressure and temperature water cannot take sulphur dioxide in excess of certain concentrations; water cannot take ammonia in excess of certain concentrations; ethylamine cannot take s to s in excess of certain concentration; it is decided by thermodynamics equilibrium right these are all equilibrium curves.

So, we have to get back to the literature and get our what do you call solubility data or certain equilibrium relations which will tell us. Given so, much of concentration in the gas phase, how much maximum or how much equilibrium concentration we have in the liquid phase that is equilibrium right. Given y how much is x. Given partial pressure of gas sulfur dioxide in one stream, how much is liquid phase concentration mole fraction in the liquid phase that is equilibrium curve. So, we get back get into some hand book or McCabe smith or Treybal’s hand out or appendix and we note down the equilibrium curves equilibrium data points and one can plot here.

But it is also important to note that there has two a very common theory or laws which are used or which have been used to determine this equilibrium relationship. One, if you recall from your knowledge may be stoichiometry you have done or mass transfer one is a Roult’s law, mostly for ideal solutions we apply and the second is Henry’s law. So, these are the two common laws one can use to determine the liquid phase concentrations given the gas phase concentration. Let us note down this.

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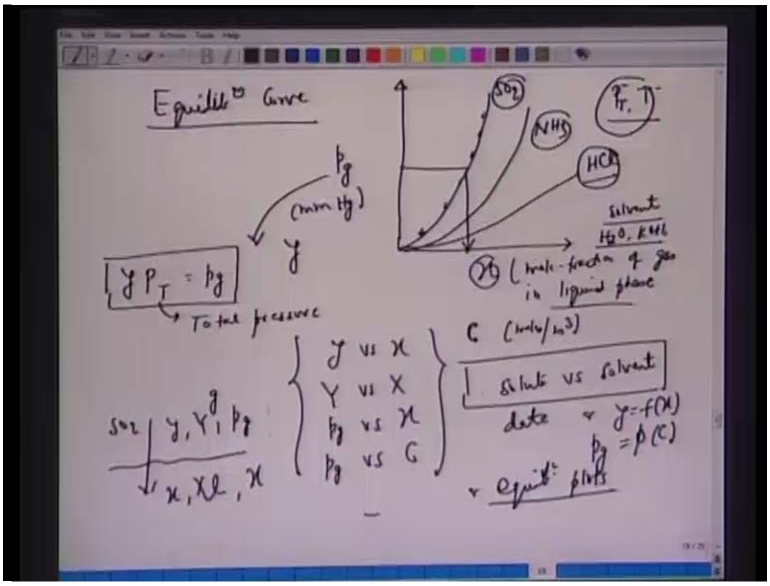

So, we are discussing now equilibrium curve because, this is our starting point here. So, we are trying to obtain or we are or we are starting from here. Given partial pressure in the gas phase say certain mille meter of mercury, how much should be X, so p g versus x or x versus p g mole fraction or gas in liquid phase. Mind you this p g can also be written in terms of mole fraction y in the gas phase. If you apply y p t equals p g, so where p t is a total pressure.

So, either you can plot y versus x or p g versus x and essentially you have some curve like this, given total pressure P T and temperature let us say we have a curve for sulphur dioxide all it means given so, much of partial pressure in sulfur dioxide in air how much will be mole fraction X in the liquid phase.

One can also instead of x 1 can also write in terms of c moles per cubic meter of the liquid phase, so different ways of writing these concentrations, either y versus x, capital Y versus x, p g versus x or p g versus concentrations or different ways of writing all these equilibrium curves. Idea is that given pressure and temperature such data are known to us from certain hand books or from certain calculations.

Similarly, we will have different curve for ammonia. Similarly, you can have a different curve for H c l. So, these are the diffusing species or transferring species or the species which absorbs in certain solvent. So, solvent may be it is water may be K o H may be H 2 S o 4 etcetera.

So, given pressure given temperature we have a system of solute versus solvent, and this is and we have the data or we have some equation y equals some function of x for p g as some function of concentration etcetera; or we have been given this equilibrium curve or some plot equilibrium plots are known to us. Either way we can plot or we can given the plot we can determine we can calculate those mole fraction etcetera.

The idea is a simple, we have gas here, there is a liquid phase, certain species transfer from one phase sulphur dioxide from here to here, this is y, this is x, this is capital Y, this is capital X, this is small partial pressure here, here small p g and here we have this x etcetera. So, these are all your equilibrium curve we starting from here. And as you said earlier that they are two very common laws if it is an ideal solution.

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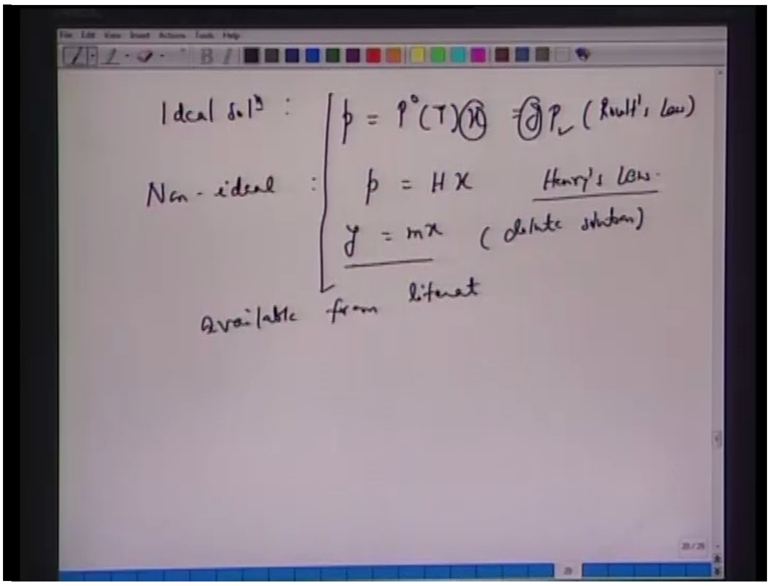

Ideal sol^n : $p = P^{\circ}(T)\,x = y\,P$ (Roult's Law)

Non - ideal : $p = H\,x$ Henry's Law

$y = mx$ (dilute solution)

available from literat

Then very often one can calculate per as p equals partial vapor pressure the given temperature into x equals y into p. So, this is your Roult's law. Roult's law can be applied to calculate mole fraction in liquid phase, given mole fraction in gaseous phase etcetera. If you know the total pressure; and if you know the vapor pressure at this given temperature here.

If the solutions says behaves as non-ideal, one can also apply Henry's law P equal to H X. This would be your Henry's law. And generally Henry's law is applicable for dilute solution, p equals H X or some form y equal to m x.

So, one can also make calculations but, generally all this data are all available from literature, and that becomes a starting point for our calculations. Now, they are certain design considerations, so one is of very important is the choice of the solvent. Now, this sulfur dioxide is s 2 s or ammonia it is possible that we have several type of solvent. So, when you design when you say process design, we have to consider what type of solvents or what choice we have for the solvent, and the choice of solvent that also require several other consideration cost availability.

Once you have treated your fluent treated your fluent gas with certain solvents then, you have to worry about the disposure, you have the spent liquor and how you are going spent it, so safety considerations right. Disposal considerations economy also plays a major role in deciding what type of solvent we have. So, again we do not focus on those aspects we assume we have chosen a certain solvent and we have the solute we referred to certain literature data for the equilibrium curves; and then becomes our starting point. But, let us note down for your educations design consideration as far as the solvents are concerned.

So, choice of the solvent oppose the first should be the gas has very should have very large solubility significant solubility, so that is the first choice, we choose water we should be have very large solubility for sulfur dioxide or for ammonia. The second is volatility volatility right, we do not want our solvent to have very large volatility. The solvent we do not want to waste, so we should have less volatility, or we can say less vapor pressure, it should not be very expensive.

So, cost consideration is another availability should be rarely available; safety that is a major consideration here because, safety plays a major role role in handling or during handling. Our gases or the liquid should not be corrosive because, if it is a corrosive then material of constructions accordingly for the pipes etcetera etcetera or the equipment it will become material will become itself major bottle neck in the design.

Viscosity also plays a major role because it is a question of transport in the pipe line all right. So, these are the some of the design considerations, one has one has to keep it in mind when you are choosing a certain type of solvent. Well that is not your intension of this course here when I am sure you have the design course at some level where you look at the cost part of it or economic part of it. So, right now in this course we are concerned with mass balance, species balance, equilibrium, drawing the operating curves, what is the solvent amount of solvent required, how many stages we require. If we have the stage wise contact; how much is height of the column if it is a continuous packed bed column like we have here so, these are the things we are going to focus in this course.