Mass Transfer II

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Lecture. # 10

In the previous class, we tried to graphically understand, how to calculate the minimum amount of solvent required in a typical absorption column. And essentially we looked at the slope and we try to decrease the slope till it intersects with a premium curve and there we said the driving force for mass transfer is 0. From that we can calculate the slope and then we can mark those points, and then we can find the 1.5 times the minimum operating conditions etcetera. But we must also understand that, whatever we can do graphically, we can also solve mathematically by writing down these equations.

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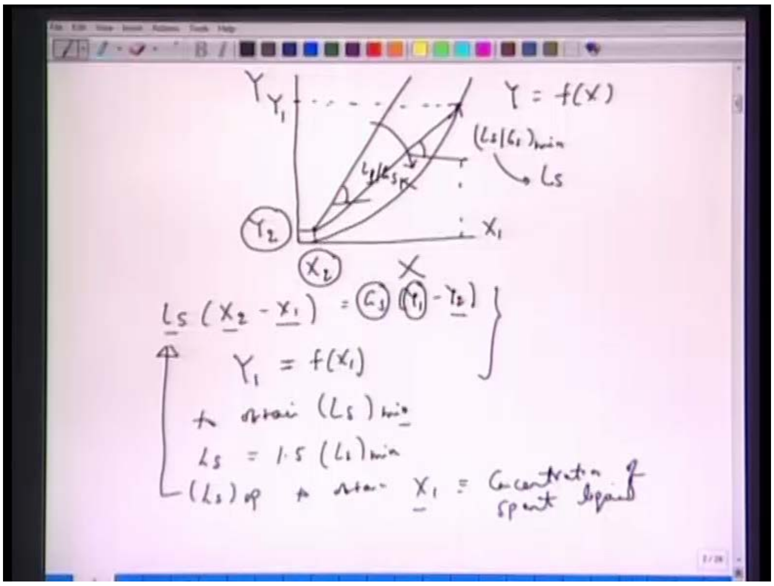

$\underline{L_s}(\underline{X_2} - \underline{X_1}) = G_s(Y_1 - \underline{Y_2})$

$Y_1 = f(X_1)$

to obtain $(L_s)_{\underline{min}}$

$L_s = 1.5\,(L_s)_{min}$

$(L_s)_{op}$ to obtain $\underline{X_1}$ = Concentration of spent liquid

Let us redraw this curve of operating lines and equilibrium curve it said that we have Y versus X. Let us assume, we have the equilibrium curve like this. So, we have been given this equations Y equal to f (X), we know these points we have X 2 and we have Y 2, so this is at the exit end and we know Y 1 to feed concentrations in the gaseous phase, and X 1 is not known here. If we draw an arbitrarily operating curve with the slope of L s by G s as this will intersect with Y equal to Y 1 here. And if it decreases this L s given G s if G s is fixed, and we want to decrease this amount L s and the slope will decrease till it reaches and intersects this Y equal to f X curve, which gives us L s by G s minimum from which we can calculate the amount of solvent required.

Let us also try to understand that, this is the operating lines. So, we can write down the equation for these operating curves as L s X 2 minus X 1 equals G s Y 1 minus Y 2. Here in this problem; the most typical problem Y 2 is given to us X 2 is known so, Y 2 and X 2 are known. Amount of G s flow rate gases phase is known Y 1 is known, so that unknowns are L s and X Y. But if we realize that, at this location where the operating line intersects this equilibrium curve we also have this equations Y 1 equals f X 1. So, here we have Y 1 equals f X 1 and one can also solve these two equations to obtain L s or L s minimum. Whatever we can do on graphically, one can in principle; one can also solve analytically etcetera. And from here we can solve L s minimum and then realizing that we have L s equals 1.5 times L s min.

We can calculate L s operating and once we know L s operating. And we can put it back in the previous equations to obtain the X 1 concentration of fluent concentration of liquid spent or the liquid fluent. Essentially, the idea of this small exercise here is that, we can solve graphically as well as we can write down the set of equations. Operating line which is linear Y equal to m x plus c form, and the equilibrium curve Y equal to F X thermodynamics two unknown two equations. We can determine the unknown quantities here. So, important thing also to note here that the shape of the equilibrium curve will be different; depending upon what type of systems we have sulfur dioxide, water, ammonia, caustic etcetera.

So, in that case there is a possibility, that certain curve which is not exactly concave downward what we have done in the previous two examples or previous two cases. There is a possibility of a pinch at locations much ahead of and that the final exit concentration which we are corresponding to Y 1, in other words let us see this graph here.

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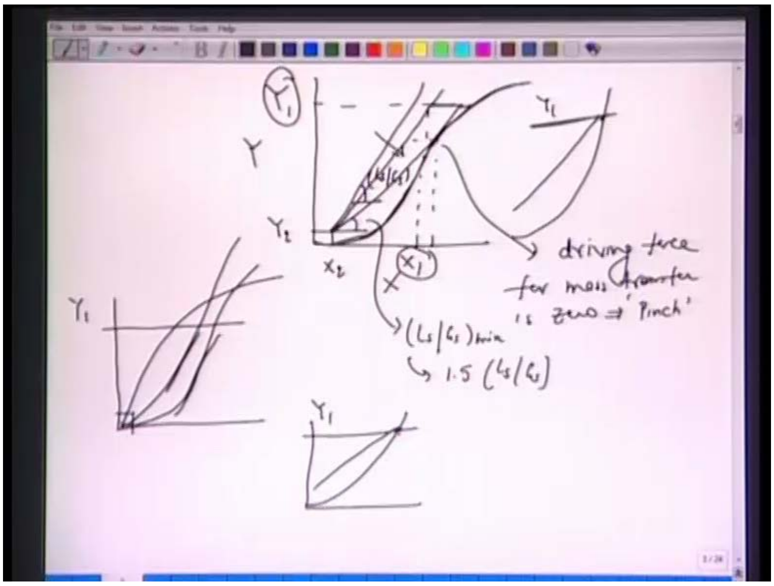

Suppose, we have equilibrium curve like Y versus X now, equilibrium curve goes like this and if we concentrate on the sum same X 2 and Y 2 which we had earlier and this Y 1 was given here at some concentrations. Now, with this if you want draw any operating curve with the slope of L s and G s, L s over G s and if we reduce the slope or in the words we are trying to find out the minimum amount of L s, we must realize that we can have a tangent here. Now, please notice the difference between the previous case, where we had the intersect here. Now, because of the shape of this curve which is not exactly concave which is not concave downward like this where we had the intersections corresponding to this Y 1 right here.

In this case the pinch occurs right here. Here the driving force comes 0 driving force for mass transfer is 0 here is 0 or what we call there is a pinch here. So, pinch occurs here rather than here. So, in other words, this will give us L s the slope will give us L s by G s min and from here again, we have to find out 1.5 times L s by G s to determine the operating curve. It will now go like this and we will get the concentrations which is X 1 corresponding to Y 1. So, idea is that, you have to be careful with the type of equilibrium curve which will vary from system to system it could be like this it could be like this it could be like this, and each case, if the Y 1 is fixed Y 2 X 2 is fix somewhere here, one has to be very careful and with the trying to find out this minimum operating curve where it is makes a tangent where the operating line makes a tangent.

The curve like concave, downward likes this and of course, there is no problem with this finding this minimum curve we can directly connect with the last point corresponding to this Y 1. We take the example, now for the two cases, one is absorptions and one is desorption or stripping. And in one case, you will see that we have a curve where there is a possibility of a pinch. So, let us take this example; very simple example of a typical absorption column, we have a flue gas which contains coal gas, which contains solid benzene and we have been asked to clean this gas coal gas with some wash fluids or wash oil.

And then, we want to mark all these operating curves, the mole fractions at the inlet, at the exit, the minimum operating curves, minimum operating line to determine the amount of solvent required. So, let us take this example to understand this equilibrium curve and operating curves.

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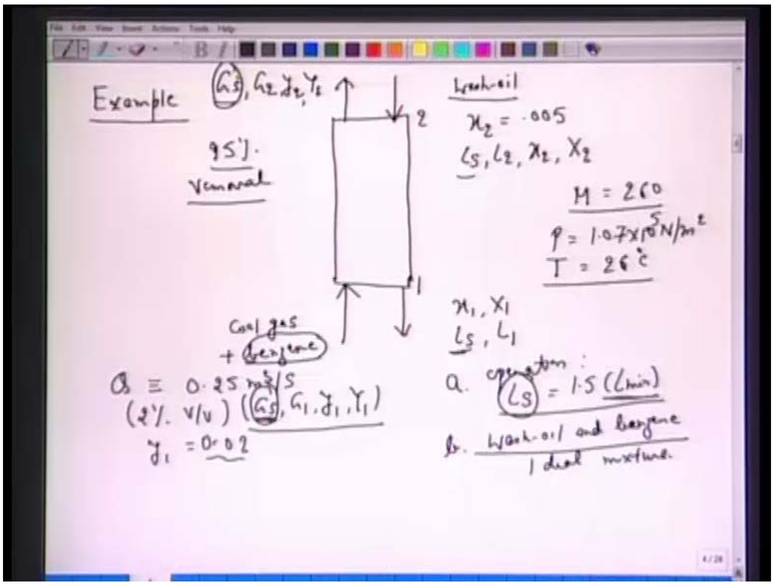

So, this is the example, of an absorption so, let us draw a vertical we have absorber and it is given that inlet. We have coal gas which contains benzene. So, benzene is a solute or transferring agent you know from one phase coal gas to this wash oil. This coal gas specification is given here that we have the flow rate Q volumetric flow rate 0.25 cubic meters per second, and this flue gas contains two percent volume by volume V by V of benzene. So, if you go by the previous nomenclature which we used, we have here G s we have G n G 1 so, this would be a solid free basis or we can call it dry gas of course, there is no moisture dry means there is no benzene based on benzene free solid free basis. So, we have G s we have G 1we have small fraction Y 1 and we have Y 1 the solid free gas.

So, these are the four quantities here typically, we have kilo mole per second or we can also have kg per second just by multiplying by the molecular weight. To clean this we have been given a wash oil, and this wash oil is not pure, in other words if this location is 2 and this is 1 here this contains small amount of benzene. So, we can say that small X 2 is given the mole fraction is 0.005. Here is two percent volume by volume so, Y 1 in this phase is 0.02. And we have been told that ninety percent removal is required; ninety five ninety five percent removal. So, we want to reduce these concentrations from of starting with 0.02 mole fractions by ninety percent. So, before we do the calculation let this mark let us the specs here G s G 2 small y 2 and Y 2.

Notice, we have G s and G s without any subscript because; amount of G s will remain the same. So, that is a carrier gas or benzene frees this coal gas which is not soluble in wash oil. Wash oil contains X 2 but we have L s amount of solvent required L 2 X 2 which is 0.005 and we have X 2. Similarly, here you will have x 1 X 1 L s and notice L s without any subscript because L s solvent solid free basis amount of solvent remains the same and then we have L 1. Certain properties physical properties are given here molecular weight of this wash oil is 260 pressure is given 1.07 10 to power 5 Newton per meter square, temperature is given 26 degree centigrade. Two important things are given here. One operation it says similar to what we did we just discuss a while ago L s solvent flow rate is 1.5 times the L minimum.

So, this should from here, we should be able to calculate actual L s. So, first before that we have to find out the minimum amount of L min require. And b it says that, wash oil and benzene, this system behaves as an ideal mixture. So, before we proceed further it is a good idea to graphically understand what we want to do. So, the most standard procedure, it is recommended that you follow the procedure that we draw this is schematic of this absorption columns it is a packed bed.

So, may be like to draw schematically like this. So, it is a packed bed signifies that there is a packing some type of packing. So, we have packed bed we mark the streams inlet outlet we put the specs there X 1, X 2, Y 1, Y 2 at the both the locations one and two.

Whatever the quantities are given, we write down 2 percent volume by volume so, we said that Y 1 equal to 0.02. Benzene oil which comes from the top right. The wash fluid contains certain amount of mole fractions so, we have 0.005 there. Volumetric flow rate is given to us Q 0.25 cubic meters per seconds. So, we marked all these points whatever given to us, and what is not given to us we are suppose to determine. Remember by graphically by graph or by analytically by writing down the equations there is no harm either the two methods will work.

Even, if we do not want to draw or determine graphically it is not a bad idea, to draw the equilibrium curves and operating curves at least qualitatively. So, before we take up let us complete; let us try to determine what the quantities which are given to us are. So, as we said y 1 is 0.02 is small fractions, so we can determine Y 1 solid free basis 0.02 over 1 minus 0.02 equals 0.0204.

So, what is this 0.024 this is nothing but kilo mole of benzene, per kilo mole of dry gas. So, notice this nomenclature or you know the terminology dry gas that does not mean that it has moisture all it means it is a benzene free gas. So, that is the meaning of dry here. So, that is the general generally it is used that this gas or this stream is a dry or it is a wet not necessarily it contains moisture, it is specified the solute which could be anything other than moisture. So, Y 1 is known here now it says that ninety five percent remover which means immediately, we can say that Y 2, this Y 2 this is 0.0204. So, that is what we calculated. And we require ninety five percent so, the remaining is 0.05. So, we have Y 2 as 0.00102, and the unit is same as what we have written here kilo mole of benzene per kilo mole of dry gas.

So, now we know Y 2, we know Y 1, small x 2 is given 0.005 mole fractions, wash oil is not pure it contains very small amount of benzene. We will talk about this in the next example. But let us find out X 2 here so X 2 would be 0.005 over 1 minus 0.005 solute free bases and this would be 0.00503. And what is the unit, unit is kilo mole. So, what is the unit here, let us note down the unit here. The unit will be very similar to what we have in case of gas phase. So, kilomole of benzene per kilo mole of wash oil, you know this oil. So, it is benzene free oil it is not the total amount so, that is the different between small y 1 Y1 X 1 and X 2. One important here is now this thermodynamics. So, If we recall first we have to draw this equilibrium curve so, equilibrium curve in case of this coal gas which contains benzene as a impurity, which we want remove by ninety five percent, to do that we have been given the solvent.

So, you will expect that we require equilibrium curve, given so much of partial placer in the gas phase given, so much of mole fraction in the gas phase, how much will be the liquid phase concentration as given by thermodynamics or solubility curve. So, you can go to some hand out, chemical engineering hand out, parries hand ball hand out, Treybal McCabe's smith, some of the text book they do give they do report solubility data at a given pressure and temperature. One can go back to these hand outs, refer do some Google search as well there is no harm to obtain this Y versus X. But remember here, it says this benzene oil it acts as an ideal fluid. If you recall couple of lectures ago we say that if its ideal fluid ideal liquid, it will behave as it will follow Roult's law.

Even, the Rout's law for the vapor pressure can be used to determine the solid, to determine the liquid phase concentration mole fraction given the gas phase concentrations. If we recall that we talk about Roult's law and we talked about Henry's law both laws. Henry's law, which we also apply if the concentration is low. Rout's law, which is used for calculating the vapor pressure. Given the composition in one phase find out how much the vapor pressure exerted by the solute can also be used to determine the solubility data X versus Y. If we assume it is an ideal fluid which is what it is given here. So, at a given temperature which is 26 degree centigrade here, all we have to do is to find the vapor pressure of benzene and then knowing the total pressure we can calculate this Y versus X curve.

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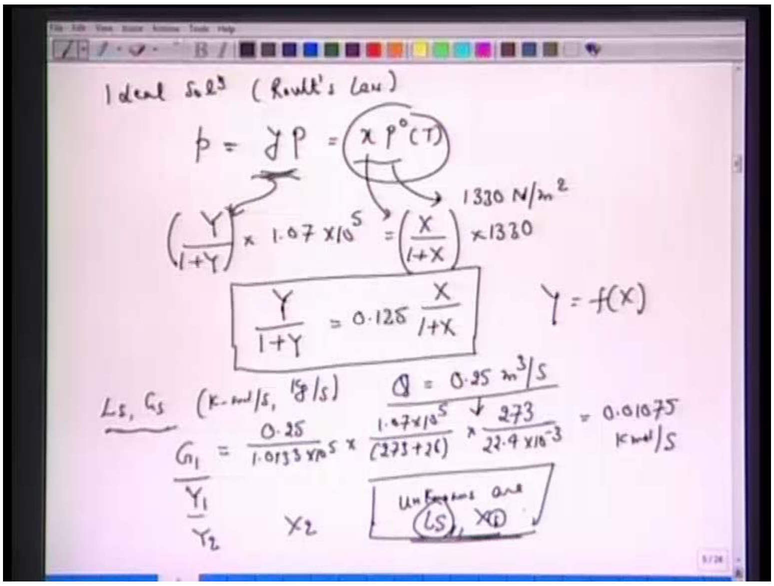

Ideal Soln (Roult's Law)

$$p = yP = x\,P^{0}(T)$$

1330 N/m^2

$$\left(\frac{Y}{1+Y}\right) \times 1.07 \times 10^{5} = \left(\frac{X}{1+X}\right) \times 1330$$

$$\boxed{\frac{Y}{1+Y} = 0.125\,\frac{X}{1+X}}$$

$$Y = f(X)$$

Ls, Gs (K-mol/s, kg/s)

$$Q = 0.25\ m^3/s$$

$$G_1 = \frac{0.25}{1.0133 \times 10^{5}} \times \frac{1.07 \times 10^{5}}{(273+26)} \times \frac{273}{22.4 \times 10^{-3}} = 0.01075\ \text{Kmol/s}$$

Y_1

Y_2

X_2

Unknowns are Ls, X1

Let us write down here that we are assuming ideal solution, and we are applying Roult’s law, which is y P equals x P 0. Now, see the difference, partial pressure equated in two phases. So, this is the Roult’s law and we have equated with this y to p partial pressure Dalton's law etcetera we can call it. So, vapor pressure at this temperature of 26 degrees of centigrade we can go back, and we can see this is given as 1330 Newton per meters square. Essentially we have y p, so we can write Y1 plus Y into the pressure is given as 1.07 10 to the power 5 capital X over 1 plus X. So, small y replaced with Y over 1 plus Y, and a small x replace with capital X over 1 plus X into the vapor pressure which is 1330. To simplify this, we have Y over 1 plus Y equals 1.25 capitals X over 1 plus X.

So, we have obtained the equation for equilibrium y as function of x. Now, before we draw the operating curve remember we are supposed to work on L s and G s, which is kilo mole per second or kg per second, either way one can write here and we talked about the advantages here that operating line is straight. Now, the flow rate is given Q which is 0.25 cubic meter per second. All we do, we convert this into kilo mole per second for the gas phase, so we have G 1 one signifies the inlet conditions, 0.25 cubic meter per second. You are applying very simple ideal gas law etcetera. One pressure corrections 1.0133 into 10 to the power 5 into 1.07 10 power 5.

So, this is the pressure corrections, to calculate at normal temperature and pressure temperature is 26 degrees centigrade, 273 plus 26 multiplied by 273. So, this give us normal cubic meter per second divide by if you recall 22.4 into 10 to power minus 3 to make this 0.01075 kilo mole per second that is G 1 . Now, our problem is over G 1, Y 1 these two are given here, Y 2 is given and X 2 is also given. So, the unknowns are the liquid flow rate and this spent liquor concentrations which are at locations 1 L s by S 1. And also, we are suppose member we said that L s has to be determined from the minimum operating conditions minimum amount of solvent required from the criteria which we discussed in the earlier classes.

Now, we are in the positions, so after doing these small calculations whatever is given to us and whatever we are suppose to determine. Now, we can draw graphically remember not necessarily, we have to solve by graphically one can write down these two equations for operating line and the equilibrium curve and one can solve by simple calculations etcetera. But its good practice it is a good idea to draw graphically and mark those points at least qualitatively. So, let us do this.

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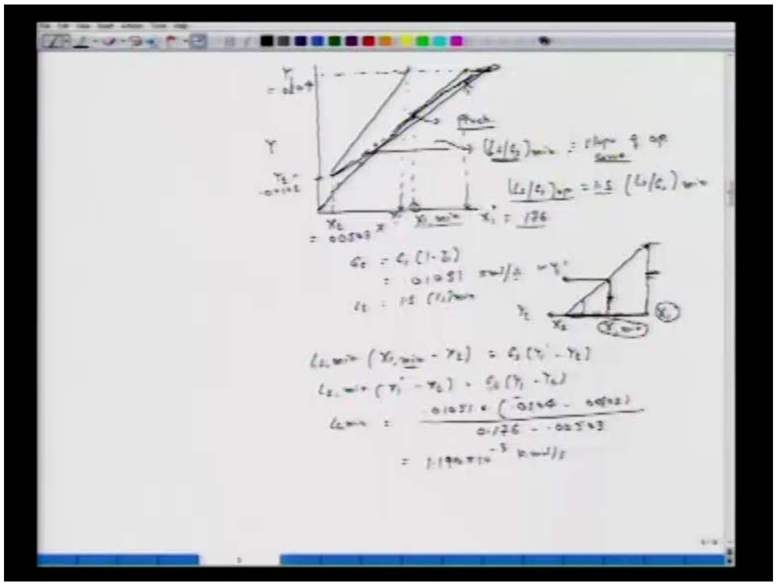

So, we have this equilibrium curve, Y versus X and if you draw carefully from the data you will see that this curve is slightly convex downward. So, the shape of the curve is not exactly linear, it is slightly convex here. You will see the importance of this curve so, one has to be careful in plotting whatever data we have chosen for Y and X or you should take as many as data possible to draw this curve very smoothly equilibrium curve here. Let us mark the coordinates here let us say this is Y 1, which is given as 0.0204 and the concentration is brought down from Y 1 to Y 2 equals 0.00102 and corresponding to this Y 2 we have the concentration of the spent liquor spent solvent which is 0.00503.

So, now once, we have X 2, Y 2 on the exercise which did earlier one has to be careful to find out this minimum amount of solvent so, you can see that there will be a tangent like this. So, these mix a pinch here. And we have discussed in the previous class previous lecture that this will give you what do we call X 1 min maximum concentration of this spent solvent. So, the idea is that if you try to connect directly from here, to let us say this point here connecting like this will give wrong results. So, one has to be careful with the shape of the equilibrium curve, which we have drawn like this to find out this pinch here. Once with this draw this tangent pinch here, we have the slope we can determine L s by G s min slope of operating curve for this minimum amount of solvent conditions. G s is fixed here, once we know this L s by G s the problem is given that L s by G s operating is 1.5 times L s by G s min.

So, then from that new slope we can determine the curve likes this and then we can do our other calculations. We can get actual X 1, which should be working here. So, let us come back to this calculations from the from the previous the values for G 1 flow rate of the gas one can determine G s first as G 1 minus Y 1, which is if we calculate point 0.01 you will get 0.01051 kilo mole per second . L s is given as 1.5 times L s min, which is as good as L s by G s operating is 1.5 times L s by G s min, because G s is fixed here k mole per second which we have calculated here. So, from here to get L s minimum amount of solvent or here suppose to get this slope here. How do we get this slope, remember this is a tangent here and this coordinate is X 1 min, this point is X 2 corresponding to which we have Y 2 here also we can have some Y prime and wherever it make intersection with the curve we have this X 1.

So, that to find slope here, this time theta either you go by this segment divided by this segment are you can go by this segment. All you have to do is read either X 1 min or X 1 here. We can write down the operating line equations at the minimum conditions as L 1 X 1 min, minus X 2 equal to G s. So, if we choose X 1 min here, we have to read G s Y prime minus Y 2 or we can also write L s min, if you read the right this coordinal. From the tangent, if you extend and suppose we read this X 1 as 0.176, we can also find the slope from here X 1 let us put a star here X 1 star minus X 2 equal to G s we have Y 1 minus Y 2. So, idea is that you know it is upto you either you this read X 1 min from the tangent or you read this X 1 star where its making this tangent or the intersection with this Y 1 line or u either the two will give the same result here. because you have to find out the slope.

So, L s min equal to 0.01051 which is the G s multiplied by Y 1 so, this is 0.0204 minus y 2 0.00102 divided by we have 0.176. So, we are rating it X 1 star here dash 0.176. So, we are rating; we are trying to find out the height of this segment divided by the entire segment, which will give the same result for the slope, if you go by this method? So, it is upto your choice 0.176 minus 0.00503 which is X 2. If you calculate you will get 1.190 10 to the power minus 3 kilo mole per second. So, this is the minimum amount of solvent required for the present conditions.

We have the equilibrium curves, which are given to us we now the operating curves, wherever there is a pinch Y will be equal to X and that point will satisfy both operating curves and the equilibrium curve. One can obtain X 1 min from there also from that then go back and put back the equations to obtain L s min but if you have a graph and you know it do it nice job then there is no need to solve analytically.

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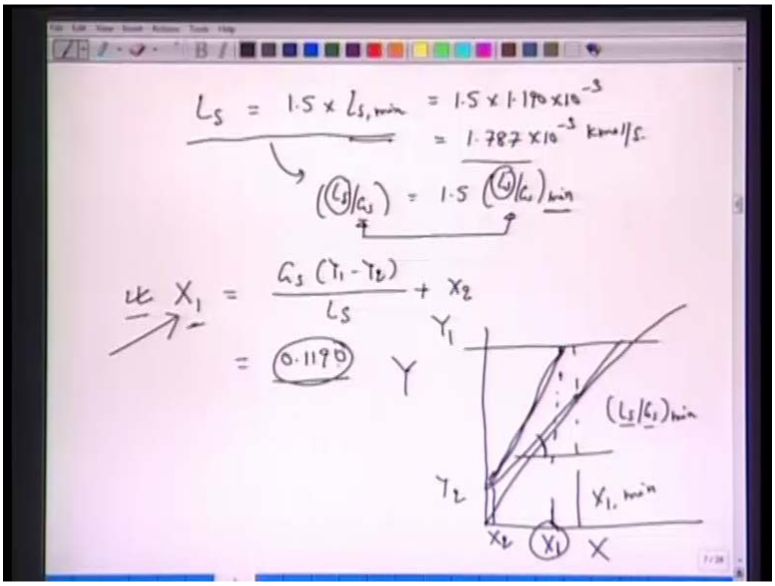

$$L_S = 1.5 \times L_{S,min} = 1.5 \times 1.190 \times 10^{-3} = 1.787 \times 10^{-3}\ \text{kmol/s.}$$

$$\left(\frac{L_S}{G_S}\right) = 1.5 \left(\frac{L_S}{G_S}\right)_{min}$$

$$\text{at } X_1 = \frac{G_S(Y_1 - Y_2)}{L_S} + X_2 = \boxed{0.1190}$$

So, now we know L s min we can calculate, L s operating which is 1.5 times L s min, which is 1.5 times 1.190 10 to power minus 3 equals 1.787 10 to power minus 3 kilo mole per second. Writing this, is same as saying that slope L s by G s equals 1.5 times L s by G s min. Why because G s is the same, they are the same, it is only L s which we are trying to find out based on this minimum conditions. So, either you go by this or you go by this try to understand the graphically. Once you know L s know again you can go back and put back in the same equations to obtain X 1 G s, same operating line. Now, we are rearranging into right G s by L s plus X 2. So, from here we know. Now, we know L s we can calculate 0.1190.

Again let us redraw the curve right here again, we have Y, we have versus X, we realize the curve is slightly convex down like this. We have marked our points which are Y 2 X 2 which is known to us we knew Y 1, we do not know the slope but problem says that we have to take 1.5 times the L s minimum. So, we draw a curve which is a tangent to this point here. This point will be of course, X 1 min and the slope will give us L s by G s min or L s min because G s is fixed, when we take 1.5 times. Now, the curve will move like this. And, the curve when move it like this is the operating curve now we will get X 2 X 1 which we have just now calculated as 0.1190.

So, if we know if we want to solve graphically, that will also work you know the slope. Take 1.5 times to obtain this line and then read from the graph to X 1 as X 1 or you solve the operating curve and the equations for the operating curve twice one for this L s min you obtain L s min take 1.5 times to knew to obtain new L s and again put it back here to get the X 1. You must do this as an exercise to see that both graphically as well as analytically you get the same results at least you should do once. Because it depends upon the type of the problems or type of the system actually the equilibrium curve may be of different peculiar shape certain very specific shape and it may not be possible to work out exactly on the graphically it is a prone to error .

Drawing the tangent etcetera, it invites some error. So, very obtain one would prefers writing a small code or a small you know programming to solve these equations. This is the way most of the commercial engineering software's like Aspin, they also work all they do they have inbuilt you know this operating curve. Very general operating equation for the operating curve, you choose a system it is a draws you know it has a equilibrium curve Y versus X, it solve these two equations under different conditions whether it is a minimum conditions or it is the operating conditions. But the idea is the same; we should have you know physical in understanding of this. We take the same example here, what we had here was the absorptions.

So, this is a transferring component from gas phase to the water, and we try to find out the minimum water flow rates minimum solvent flow rates and then we took 1.5 times. Now, we can have the different case desorption or the stripping. In that case typically it is a liquid flow rate which is given and one has to decide the gas phase flow rate. There also we can have the condition that its gas flow rate is now 1.5 times the minimum conditions. In that case, we will see what happens to the operating lines and what happens to the equilibrium curve, where are these points? We take this example of stripping column, which is which follows absorption column so, stripping column or what do we call desorption column.

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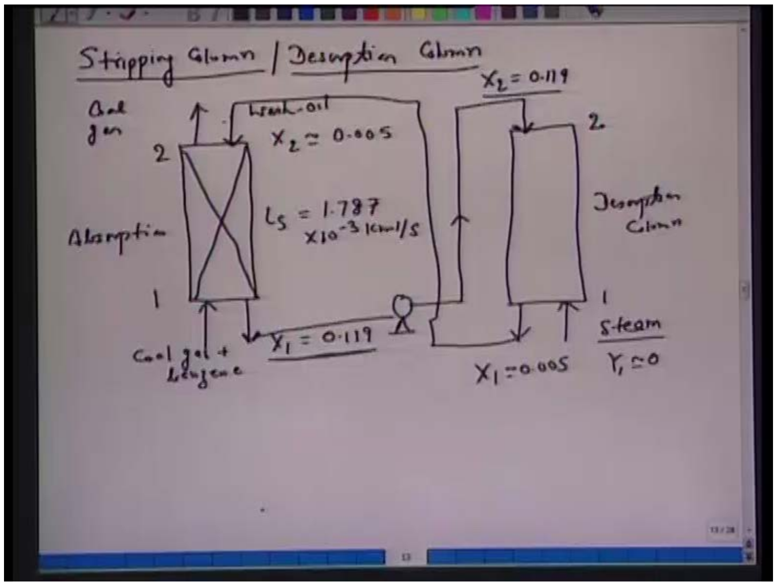

Stripping Column / Desorption Column

So, we continue with the previous example on absorption. So, what we had here we had the coal gas which contained benzene and this gas was cleaned with wash oil. So, we had wash oil and here the concentrations x 1, which we calculated was 0.119, the flow rate of this wash oil was given was calculated at 1.787 10 to the power minus 3 kilo mole per second. And we had this X 2 given as 0.005 so, this was first 2 this was 1 so, we address this absorption column in the previous example. So, now what happens this liquid which is rich in this benzene now, this has to be stripped, it has to be removed of benzene. So, essentially we have one more column in series with this and now this spent liquid now, this is pumped and brought as feed or inlet to this column. So, this is absorption column and this is desorption column.

So, the idea here is that, this liquid which contains very high amount of benzene 0.119, so, this is same as this composition here, this is cleaned with steam. So, in a typical power plant we have plenty of steam available composition here is 0, so it is a pure steam this level is 1 because this is level is 2 this is steam is used countercurrent to this liquid to clean this benzene. So, that this fluid now this contains X 1 this amount has 0.005 and this liquid now, can be fed to this absorption column. So, try to understand what we want to achieve in this desorption column. So, typically what we have in an industries, that we have this flue gas which was here coal gas containing benzene and we were ask to clean this coal gas. So, to do this we had wash oil as a solvent but the solvent is quite expensive.

So, when this wash oil is used counter currently to remove this benzene from this flue gas, then this spent liquor contains very large amount of benzene. Now, this is spent liquor has to be clean again by different solvent and fed back to the absorption column, because this solvent is quite expensive, so typically in a power plant we have a steam. Now, we take this outlet from the first column liquid has a feed to the second column which we calling it, desorption column. Here, we use a steam counter currently, so we have the mass transfer and now this wash this oil which was spent liquor which contain very high amount of benzene. Now, it is strip out benzene now we get a nearly very pure solvent and this solvent is now going to be fed back to this previous column.

So, we had absorption in the first column, now we have desorption in the second column or we have stripping in the second column. The first problem we were given that liquid flow rate is 1.5 times the minimum, now here it is given that gas flow rate 1.5 times the minimum flow rate because the liquid flow rate is fixed. Remember in the first case, it was the gas amount flue gas which was fixed it was given to us and you were asked to find out what is the liquid amount. Now, in the second case it is the spent liquor so, we know the flow rate of it, so the flow rate of the liquid is known and we have been asked to calculate the gas amount given that it is a 1.5 times the minimum flow rate. So, the similar problem but now, we had earlier we had absorption now it is desorption’s. Now let us get back to this problem

This is 1 this is 2 X 1 is 0.005; note that this composition is same as these compositions. And here we have X 2 0.119 which is same as X 1 equal to 0.119, it is a pure steam Y 1 equal to 0.01 sorry here it should be x 1, if you recall; we had this mole fraction as 0.005

so, X 1 solute free basis is 0.00503. This temperature is given 120 degree centigrade and one atmosphere, the liquid flow rate here is given but G s we have to find out, and it is given that this G s is 1.5 times G s min. So, this is just reverse to what we had in case of absorption column, where we said that liquid L s is 1.5 times the minimum amount of liquid.

So, we have the similar procedure here. We follow what we did in case of earlier first we will draw the equilibrium curve, equilibrium can this equilibrium comes from Rout’s law. If you recall earlier that, we assume that benzene oil is an ideal fluid. So, we applied Rout’s law to calculate the amount of liquid in the solvent in the liquid phase on mole fraction in the liquid phase given the mole fraction in gas phase. So, given Y what is X we made use the Rout’s law. So, we apply the similar law, Rout’s law here, however the temperature here is now 120 degrees centigrade so, we have to go to the hand book and get the vapor pressure of benzene at 120 degree centigrade. So, let us draw the equilibrium curve.

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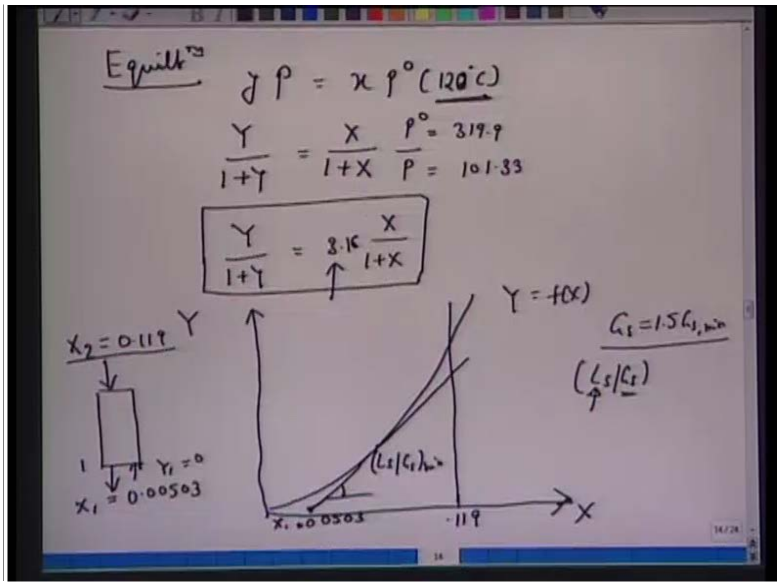

So, we have this equilibrium curve given as y P equals X is 0, however the vapor pressure has to be calculated at 122 degrees centigrade for 120 degrees centigrade. So, the y mole fraction is Y over 1 plus Y equals we have X over 1 plus X P 0 over P is P 0 vapor pressure is 319.9 and this P is atmospheric pressure is 101.33. So, we have the equilibrium curve, Y equals 1 plus Y as 3.16 X over 1 plus X. So, this expression is similar except the coefficient is now is different because of difference in this temperature now we have 120 degrees centigrade. And the less so now with this now we can plot Y versus X. So, we have the similar approach or we address absorptions now we can draw Y versus X, now if you draw this very carefully its slightly concave here.

So, we have drawn Y equals f (X), now we are going to mark certain points Y 1 X 1 and Y 2 X 2. So, if we recall in this desorption column, we know the concentration of X 1 liquid at the exit. Because this is the fluid which is going to be send back to the absorption column and this X 1 was given as 0.00503 and solvent is pure so, Y 1 is 0. So, we can mark this point here where we have this 0.00503 X 1 equal to 0.003 , now what is given to us is G s is 1.5 times G s min.Just compare this to L s equal to L s 1.5 times this L s minimum. Now, again here to obtain this minimum amount of solvent of course, we realize that we have to take a slope of L s by G s.

L s is known to us it is given to us, however G s is not known to us. We know the concentration here now this is X 2, this X 2 is 0.119 this concentration is same as what we had the concentration of this spent liquor from the column one absorption columns. So, we can mark this X 2 as 0.119, just compare again earlier we use to mark here Y 2 because that was the absorption column that was the conditions given to us now we know 0.119 here. And, to tend this minimum, if you recall again we have to take a tangent because we can see a pinch here. So, we have a pinch here which will give us 0 driving force and we can get L s by G s, corresponding to the minimum G s flow rate. Now, before we calculate let us try to understand what happens to the slope of this curve.

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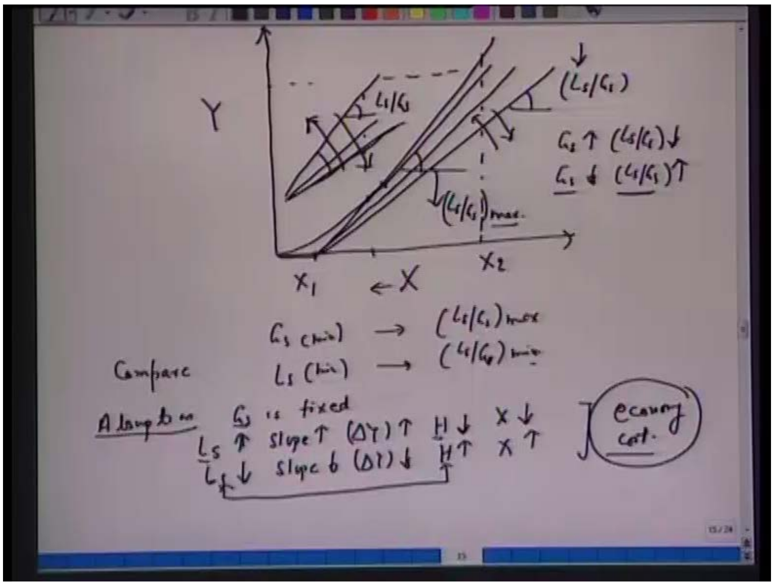

This curve here Y versus X and try to understand how does this differ how does the slope change, if we have absorption and in one case in another case we have desorption. If this is a curve and if this is a point here and suppose we draw any arbitrary curve L s by G s with the slope L s by G s. This is our X 2, and this is our X 1, Y 1 is 0 it is a pure steam. This is slope L s by G s. Now in this case try to recognize that L s is fixed and G s is allowed to vary. So, if we increase G s if we increase G s, then the slope L s by G s will decrease, and the curve will move in this direction. These are operating curve it is going to move in this directions. If we decrease G s then slope L s by G s will increase and this slope will move in this directions.

So, what happens suppose the slope moves in these directions with decreasing G s. So, when G s decreases look at the moment of the slope tell there is a point when it makes a pinch here. So, this point where it makes a pinch this will give us L s by G s which is maximum. So, make a difference make a note here, L s is the numerator G s in the denominator. Now, we are getting a slope which is maximum, we are looking for G s min, which we obtain from L s by G s maximum. Compare this to previous case, where we had L s by minimum which we obtain from L s by G s min. Again let us compare the 2 absorption and desorption, in case of absorptions we said that G s is fixed.

So, if G s is fixed and L s increases slope increases. So, recall the previous situations where we had moment of L s by G s, like this or like this. Here the G s amount was fixed so, we have increase L s by G s, the curve will move in this direction. If L s increases slope increases , the slope increases then the driving force del Y increases, height decrease because now we have large driving force, so we require smaller height to achieve this concentrations and if H increases look at this moment of X mole fractions. If we increase the slope from here to here to here the concentration of X will move in this directions or concentration spent liquor will have will be dilute or will have small concentrations .

On the other hand if we increase, decrease L s for a given G s, then slope decreased driving force decreased, height of the column increased and X increased. So, look at the economy here L s H and L s H. If the amount of L s decreases, height increases, if the amount of L s increases solvent requirement then the height decreases. Of course, there is a economy, there is a cost involve cost involve of course, we do not address too much on economy and cost in this course you will have an opportunity to address this aspect in design course. So, all we are trying to address mass transfer; we are restricted to mass transfer concentration but you can see how does the economy or how does the cost make a difference. If you take a very large amount of solvent in the absorption column, then height of the column will decrease because we have more driving force.

If we take a small amount of the liquid, then the height will increase so, there is optimization the cost etcetera. Similar situations, we have now in case of desorption columns. Now, in case of desorption now in L s is fixed solvent flow rate is fixed we have been ask to vary the G s and now look at the moment of slope. Now, the slope is going to make a tangent when it is maximum. So, to avoid this we have been told that G s is 1.5 times of minimum so, L s by G s will now decrease if G s is 1.5 times and L s by G s will be 1 over 1.5 times and this is the way the driving force will also decrease and the height of the column will decrease. So, let us sum up of this before we come back to these calculations.

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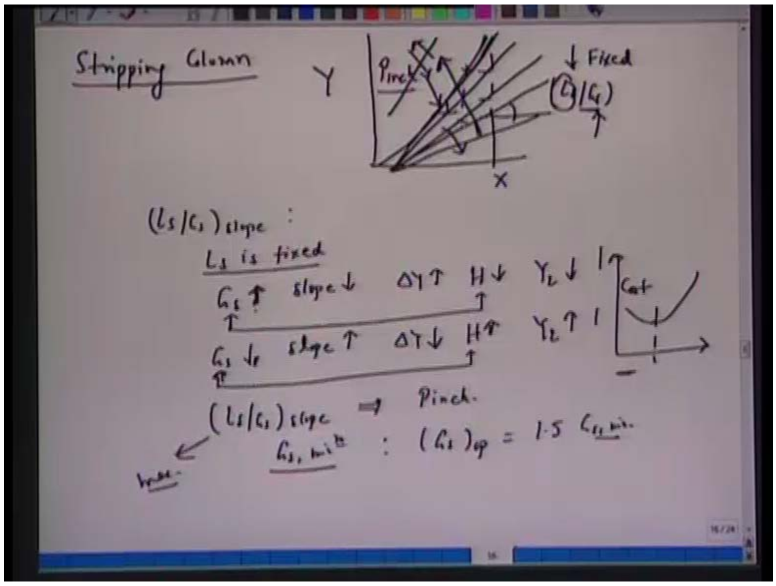

Stripping Column

$(L_s/G_s)_{slope}$:

L s is fixed

$G_s \uparrow$ slope $\downarrow$ $\Delta Y \uparrow$ $H \downarrow$ $Y_2 \downarrow$

$G_s \downarrow$ slope $\uparrow$ $\Delta Y \downarrow$ $H \uparrow$ $Y_2 \uparrow$

$(L_s/G_s)_{slope} \Rightarrow$ Pinch.

$G_{s,min}$: $(G_s)_{op} = 1.5\ G_{s,min}$

So, here in case of now we have, a stripping column or desorption column. So, this good to redraw the curve here and let us see the slope of this two, three like this. So, this is the way it moves and this is L s by G s. Now L s is fixed and we change G s so, if L s by G s that is the slope we want to address L s is fixed if L s is fixed let us increase G s. If G s increases, slope decreases see the curve will move in this directions slope is decreasing like this. Slope decreases, driving force increases; height decreases and Y 2 will also decrease. So, we have Y and we have X, so given X 2 now Y 2 decreases. So, again we see a cost effect here, large amount of solvent is required steam is required at the cost of a smaller height. If we take a small amount of G s then slope will increase L s by G s and it will approach equilibrium curve, so the driving force will decrease as this slope operating curve moves in this direction as it approaches equilibrium curve.

So, the driving force at any location this difference decreases height will increase and the same time the concentration of Y 2 exit steam this will also decrease. Again we see this cost effective. So, one can also do some cost analysis to see that there is optimum amount of G s or the amount of the height of the column which will give us desired result here now we restrict our discussion to the mass transfer in the design course some course in design may be third or fourth here level we are going to address this aspect you will make some cost balance etcetera. We are in this situation when we approach the equilibrium curve there is a risk of this operating line making a tangent with the slope with the equilibrium curve where we what we call we have the pinch.

So, we get L s by G s from here the slope from the location at the pinch locations and L s is fixed so, we get G s minimum so, all it says we cannot any amount of G s smaller than in this slope of this curve. This gives us G s minimum from here we can get G s operating equal to 1.5 times G s minimum so, see the difference L s by G s is now maximum here un unlike in case of absorption column L s by G s was minimum although G s is still 1.5 times the G s minimum.

We must understand the way operating line moves in the stripping column as when increase or decrease the flow rate of G s because L s is fixed in case of absorption column now we have G s is fixed and operating curve moves in this direction or in this directions away from this equilibrium curve depending upon whether we are taking small amount of L s or large amount of L s. So, once we have identified this now let us get back to our numerical calculations.

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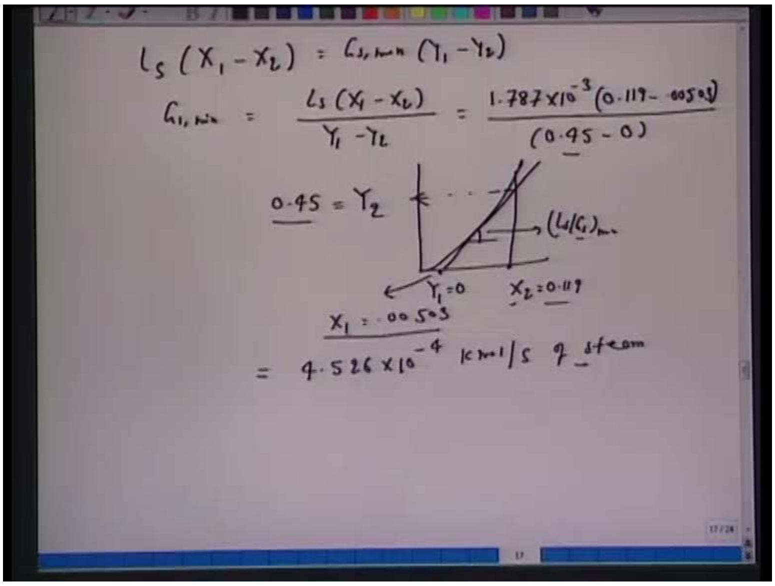

$$L_s(X_1 - X_2) = G_{s,min}(Y_1 - Y_2)$$

$$G_{s,min} = \frac{L_s(X_1 - X_2)}{Y_1 - Y_2} = \frac{1.787 \times 10^{-3}(0.119 - .00503)}{(0.45 - 0)}$$

$$0.45 = Y_2$$

$$X_1 = .00503$$

$$= 4.526 \times 10^{-4} \text{ kmol/s of steam}$$

We can write down now the operating line equation which was L s X 1 minus X 2 equals G s min, Y 1 minus Y 2.So, G S min we can find from here L s X 1 minus X 2 over Y 1 minus Y 2 and L s was fixed at 1.787 10 to the power minus 3. We have X 1 0.119, this is the concentrations X 1 minus X 2.So, this would be 0.119 minus 0.00503 so, divided by y 1minus Y 2 which is 0.45 minus 0 so, how do we get this 0.45, that would be your equilibrium curve from here, we have drawn this tangent and we had this X 2 which was given to us X 2 this was given to us at 0.119 from the slope L s by G s min corresponding to, so this minimum amount of G s we have this curve this point given as Y 2.

So, this is the Y 2 which we have got at 0.45, this is Y 1 which is 0, Y 2 minus Y 1. Essentially we have flip this and we have 0.119 and we have 0.00 very small amount this X 1 has 0.00503. So, from this slope, wherever it makes this intersection here this tangent here and X 2 is fixed we get Y 2 the substitute here to obtain this G s min as 4.526 10 to power minus 4 kilo mole per second of steam. There is a minimum amount of a steam required. Here the of course, the driving force will become 0. Again, we said in the last class that either it is a graphically or it is a numerically both should try as an exercise to obtain the same results.

If you have a drawn in graph then from there it should be careful to draw this correct tangent take this minimum L s by G s and, then from there you get G s minimum and then take 1.5 times to obtain this new slope or you can still write down the operating balance, the equation of this operating curve, equation of this equilibrium curve and find out where it makes a tangent, you can do the calculation you can write down the short programming also. Either way it can be done but you must try both ways to convince yourself that you are getting the same answer.

So, G s min is given and so, we have actual flow rate of G s solvent 1.5 times, 4.526 10 to power minus 4 as 6.79 10 to power minus 4 kilo mole per second. So, now we have the new G s, that means now we can draw L s by G s, new L s by G s so, this is your L s by G s operating curve and if you draw it carefully then from this X 2 now you will get the desired Y 2, which should be 0.3 kilo mole per mole per kilo mole. From the graph we can get directly if we have know this slope take 1.5 G s take a 1.5 time, so L s by G s will be 1 over 1.5 times. We can draw this slope wherever intersects this particular line this will give you y 2 as 0.3 or again you can go back to the equations which we wrote here. The operating line equations from here also y 2 can be calculated directly, y 1minus L s by G s, X 1 minus X 2 equal to 0.3 kilo mole per kilo mole.

So, both of them will give the same result, either you do graphically or you try to do this calculations. So, this is the value of G s L s was fixed, Y 1 X 1 X 2 everything is fixed. So, this is the example we had in case of absorption and desorptions. The idea is equilibrium curve is the same in case of absorptions operating curve falls gave up the equilibrium curves in case of desorption operating curve falls below this equilibrium curve that is one difference. In case of absorptions generally amount of G s is fixed, flue gas how much quantity we want to remove; we want to clean that is fixed and we have been asked to find out optimal L s, optimal means we have to decrease the L s minimum amount of L s.

Follow this slope of the curve it hits the equilibrium curve process will stop driving force becomes 0, we get L s by G s minimum to take 1.5 times as an operating lines. In case of stripping column amount of L s is fixed. Because now we have the spent liquor from the absorption column this has to be treated and send back to that previous column because solvent is very expensive you cannot throw it away like this. So, we have a steam relatively easily available in a power plants less in expensive. So, we make use of steam we clean this spent liquor. Now when we are cleaning it cleaning it is a desorption's now, the benzene transfers or diffuses from liquid phase to the gas phase.

Now, L s is fixed and G s we are trying to change so, when we try to change the G s. Now the slope is going to if we keep on increasing if we keep on decreasing the G s, then slope will increase and, there is a possibility of this cooperating line hitting this equilibrium curve or intersecting on making a tangent, depending upon this shape of this curve that gives us L s by G s corresponding to minimum G s, mind you L s by G s is now maximum earlier L s by G s was minimum L s was also minimum. Now, G s is minimum, but L s by G s is maximum. From there we get minimum G s you take 1.5 times stay away from this equilibrium curve stay away from this tangent from there you calculate G s and also make a note that there is always a cost economy effect.

Although, we did not do any calculations, if you try to increase the amount of liquid in case of absorption height of the column will decrease but you have to pay for a larger price of this solvent in case of desorption column if you take large amount of steams. You are going to pay for this steam; we have the similar situations height of the column will decrease because the driving force increases. So, there is always a cost on the economy one has to consider cost also will you take up this design course extension of this course may be in the third or fourth year levels. So, this was example for mass transfer and equilibrium, next class we take it we address hydrodynamics.