Mass Transfer II

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Lecture No. # 12

In the previous lecture, we defined two parameters, numbers of transfer unit and height of a transfer unit to design or to find or to determine the height of a column. So, we said that number of transfer units should be seen as the degree of difficulty in separations. In other words, if you want to purify a gas, gas is a stream say from 10 percent to 30 percent, 40 percent then the entire absorption column can be divided into several number of units, and each units we achieve a certain degree of rectifications or separations. And then we came out with the mathematical expression for number of transfer units as some integral, which we simplify to say that this equals y 1 minus y 2, that is total overall composition change over divided by the average driving force for mass transfer.

So, in other words; if you have a large number of transfer units all it reflects that we have a very small mass transfer driving force for a given separation desire. At the same time, if you say that this absorption column is equivalent to very fewer number of transfer units, we are trying to say here that the average driving force for the mass transfer is quite significantly higher there. Similarly, we defined height of transfer units, if you have one absorption column, divide into 5 number of transfer units; each transfer unit has a height, how much height we required to achieve desired degree of separations and height of a transfer units, we also said that mathematically, it was shown to be equal to or define as the ratios of the flow rate; gas flow rates over mass transfer coefficients or volumetric mass transfer coefficients Kg a.

All it means that if you have large mass transfer coefficients, because of say large Reynolds number then we have then the height of a transfer unit is the small. We require only a small height to achieve separations or to improve this purity. Similarly, if you have a larger interfacial area between the two phases - gas and liquid, then we have a smaller mass transfer height STG, and the product of two numbers of transfer units and height of transfer units gives us the total height of the column. Now, if you go back to that lecture, we obtained this expressions based on the gaseous phase.

We did the species balance or we wrote down the operating condition; operating line for gaseous phase. In principle it is possible to come out with the similar expressions for the liquid phase concentrations. So, that means number of transfer units; height of a transfer unit can be written for the gaseous phase, it can also be written for the liquid phase and can also write it for overall mass transfer coefficient or bulk quantities. In this lecture, we will write down this number of transfer units, the height of transfer units in the different ways, giving us the same results and then we will take a few examples.

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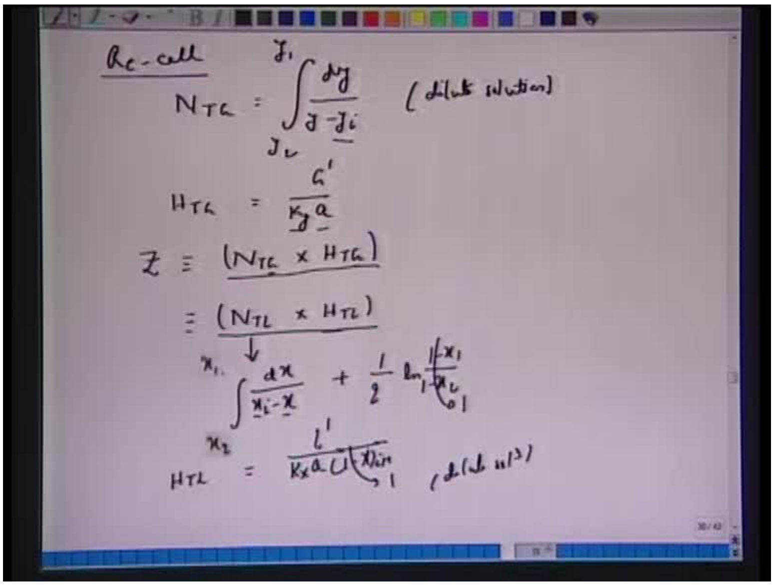

Re-call

$$N_{TG} = \int_{y_2}^{y_1} \frac{dy}{y - y_i} \quad (\text{dilute solution})$$

$$H_{TG} = \frac{G'}{K_y a}$$

$$Z \equiv (N_{TG} \times H_{TG})$$

$$\equiv (N_{TL} \times H_{TL})$$

$$\int_{x_2}^{x_1} \frac{dx}{x_i - x} + \frac{1}{2} \underbrace{\ln \frac{1-x_1}{1-x_2}}_{\to 0}$$

$$H_{TL} = \frac{L'}{K_x a \underbrace{(1-x)_{iM}}_{\to 1}} \quad (\text{dilute soln})$$

So, recall in the previous lecture, we had N T G as dy over y minus y i from y 2 to y 1 and this is for assuming dilute solutions simplified case we have dilute solutions and we had H TG, G prime over K y a. So, the total height of the column Z is a product of N T G multiplied by H T G. So, G signifies here of the gaseous phase and T for the total height of the columns. So, Z N T G into H T G and we are saying that we can also write as N T L into H T L. So, in other words this N T L can be written as or can be shown to be equivalent leave this as an exercise just make an analogy between the gas phase and the liquid phase one can also obtain this as x 1 to x 2 dx over x i minus x, so see the difference y minus y i.

Now, we have x i minus x i and that means we have neglected 1 minus x 1 over 1 minus x 2 as 1 for very dilute solutions. Similarly, this H T L this quantity here can also be written as L prime over K x a, so notice this K y a that means, we had a quantity here 1 minus x logarithmic average of interfacial concentration with the mole fractions, so which has been taken as 1, if you assume it is a dilute solutions. So, in both ways whether you work on the gas phase or on the liquid phase, we should be able to obtain the same results for the total height of these columns.

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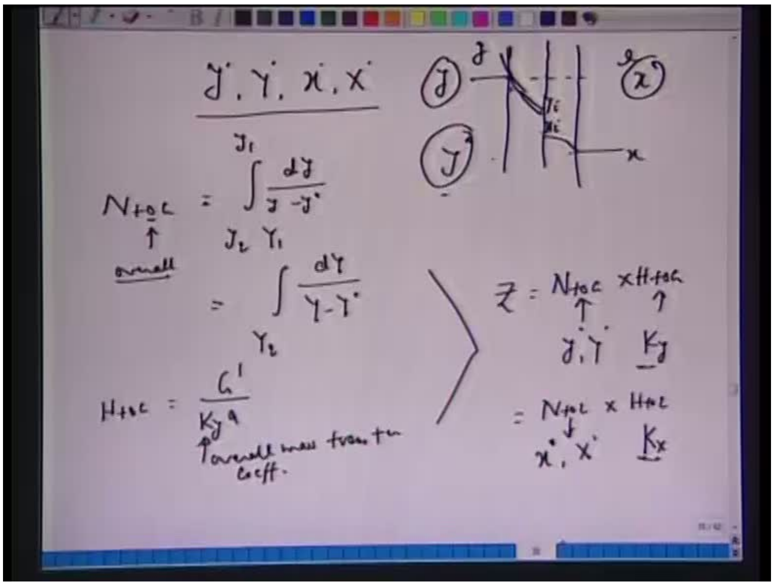

y^*, Y^*, x^*, X^*

$N_{toG} = \int_{y_2}^{y_1} \frac{dy}{y - y^*} = \int_{Y_2}^{Y_1} \frac{dY}{Y - Y^*}$

$\uparrow$ overall

$H_{toG} = \frac{G'}{K_y a}$

$\uparrow$ overall mass transfer coeff.

$Z = \underset{y^*, Y^*}{N_{toG}} \times \underset{K_y}{H_{toG}}$

$= \underset{x^*, X^*}{N_{toL}} \times \underset{K_x}{H_{toL}}$

We will one can also define this N T G and N T S G based on bulk concentration, that is y star or capital Y star or x or capital X star. So, all of this based on this bulk quantities, one can also obtain number of transfer unit or height of transfer unit. So, if you recall that we have the interface and then the concentration drops heights, so there is some bulk phase then drops here, then in the liquid phases drops then we have bulk phase for the liquid and we have this gas phase. So, we have y, we have x, y i and x i. So, for given y, if you recall we can have x star and for given x, we can have y star, that means this one can also obtain as N t o G, number of transfer unit as y 2, y 1, dy over y minus y star, so notice here now we are using N t o G, o means overall.

So, that means we have a avoided working on y i interfacial concentrations and instead of this, we work on x star and y star, so x star would be equilibrium concentrations as if the entire bulk phase concentrations is brought to this interface in equilibrium with this bulk phase concentration. Similarly, we have y star for a given x. So, we can also define N t o G instead of N T G working on y star instead of y i or if you want to work on solute-free concentrations capital Y to capital Y 1 then this becomes dy, y minus y star, which means analogous to this we will have H t o G, which can be written as G prime capital K y a, so this is overall mass transfer coefficient based on the gas phase. So, even these two should give us the same results Z equal to N t o G multiplied by H t o G, the difference comes here o, o through y star or y star and capital K y as overall mass transfer coefficients, so which means one can also define as N t o L multiplied by H t o L working on small mole fraction x star or capital X star and then we can have overall mass transfer coefficient based on this liquid phase.

So, several ways of there is writing here for determining this height of a absorption columns Z equal to N T G multiplied by H t G equals N t L multiplied by H t L, that will also equal to N t o G multiplied by H t o G, that will also be equal to N t o L multiplied by H t o L. The idea is the same, which we did in couple of lectures earlier when we discussing this interface. Generally, we want to avoid working on this interfacial concentrations y i and x i, which cannot be measured, so instead of working on y and i x i, we have y star and x star or we have instead of working on individual mass transfer coefficients k y and k x, one can work on capital K y overall mass transfer coefficient based on the gas phase or overall mass transfer coefficient based on this liquid phase.

Either ways depending upon type of problems or the quantities, which are known or which we can evaluate, one can obtain this height of this column. The main idea is we must understand that is an approach, it is an approach in which case height of a column or column has been divided into several such small transfer units. Larger the mass transfer larger the driving force, we have a small number of units and larger the mass transfer coefficient base depending upon the Reynolds number height of a transfer units also smaller, so that is the most fundamentals and basics you must understand the meaning of this meaning of this and definition the mathematical expression, which we obtained for N T G and S T G etcetera.

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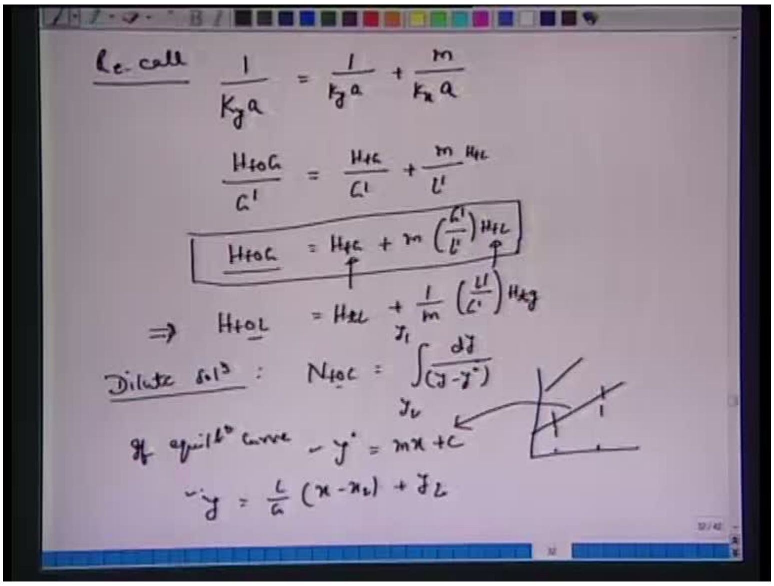

Re-call $\frac{1}{K_y a} = \frac{1}{k_y a} + \frac{m}{k_x a}$

$$\frac{H_{toG}}{G'} = \frac{H_{tG}}{G'} + \frac{m H_{tL}}{L'}$$

$$\boxed{H_{toG} = H_{tG} + m\left(\frac{G'}{L'}\right) H_{tL}}$$

$$\Rightarrow H_{toL} = H_{tL} + \frac{1}{m}\left(\frac{L'}{G'}\right) H_{tG}$$

Dilute sol^n : $N_{toG} = \int_{y_2}^{y_1} \frac{dy}{(y-y^*)}$

If equil^m curve - $y^* = mx + c$

- $y = \frac{L}{G}(x - x_2) + y_2$

Just to recap here, if you recall again we had k y capital A mass transfer coefficient as individual gas fill mass transfer coefficient plus m slope of the equilibrium curve k x a and then we can write H t o G, so this is definition we wanted to point out here that H t o G equals G prime k y a; G prime over k y a, which is H t G over G prime plus m and k x can also be written as k x a, L prime H T L. So, H t o G one can also write as H T G overall mass overall height of transfer units based on the gas phase equals individual H T G based on the gas phase plus m G prime over L prime, so essentially you are multiplied by G prime both sides of expression m G prime, L prime H T L. So, this is another way of you know writing this H t o G in terms of H T G and H T L.

Similarly, one can also show that H T O L, height of a transfer unit based on overall this liquid phase will equal H T L individual 1 over m L prime over G prime H T G, so this is a different ways of writing this. We take some special cases here that as given in the text dilute solutions of course we are discussing here that N t o G; we are writing as y 2 y 1, so N t o G overall mass overall transfer units. So, this will equal dy over y minus y star. So we do not have any other terms, because we are assuming it’s a dilute solution. Now, if equilibrium curve is linear, sometime it happens that over the concentration range equilibrium curve is linear, that means we can write as y star m x plus c.

We have the equilibrium curve, which is linear or may be linear over certain range. In this case, we can write down this equation of this curve as y star equal to m x plus c then, if you want draw this operating curve, which is y equals L by G x minus x 2 plus y 2.

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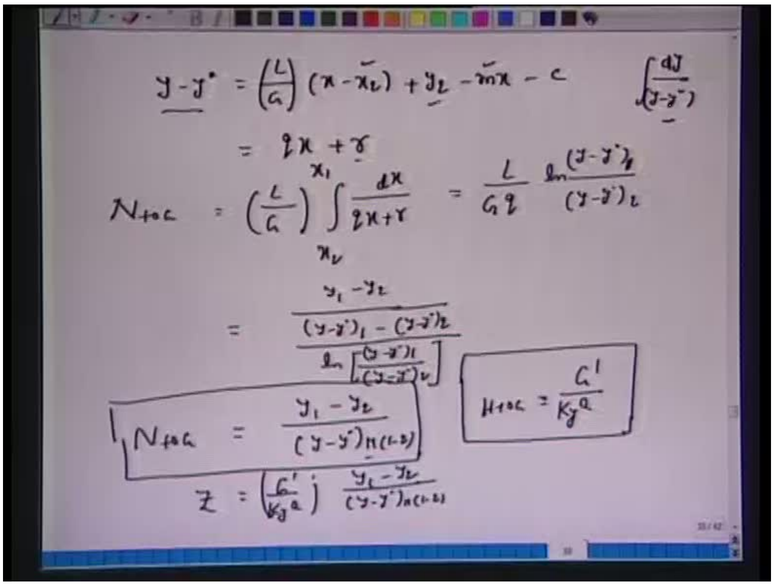

$$y - y^* = \left(\frac{L}{G}\right)(x - x_2) + y_2 - mx - c \qquad \int \frac{dy}{(y-y^*)}$$

$$= qx + r$$

$$N_{toG} = \left(\frac{L}{G}\right) \int_{x_2}^{x_1} \frac{dx}{qx + r} = \frac{L}{Gq} \ln \frac{(y-y^*)_1}{(y-y^*)_2}$$

$$= \frac{y_1 - y_2}{\dfrac{(y-y^*)_1 - (y-y^*)_2}{\ln\left[\dfrac{(y-y^*)_1}{(y-y^*)_2}\right]}}$$

$$\boxed{N_{toG} = \frac{y_1 - y_2}{(y-y^*)_{M(1-2)}}} \qquad \boxed{H_{toG} = \frac{G'}{K_y a}}$$

$$Z = \left(\frac{G'}{K_y a}\right) \frac{y_1 - y_2}{(y-y^*)_{M(1-2)}}$$

So, this is our operating curve and this is equilibrium curve one can substitute one from the another as y minus y star equals L by G, x minus x 2 plus y 2 minus m x minus c. So, we are trying to evaluate this integral for N t o G at dy over d minus y star. We are trying to see, if we can obtain an analytical expression. So, in this case when, we have the dilute solutions plus the equilibrium curve is linear then we can write y minus y star as this, you should be able to recognize that this also form of q x plus c, everything is a constant here x 2, m, y 2, L by G ratios given L by G, so we have y minus y star as q x plus R. Now, one can go back and integrate expression for N t o G to obtain L by G x 2 2 x 1 dx and we have q x plus r.

So, actually instead of q x plus C, lets us to use q x plus r for all the constant y 2 minus c L by G x 2 that is r here constant instead of c, so we have L by G, x 2 to x1, dx by q x plus r. One can again integrate this to bring L over a q L n, y minus y star at 1 over x minus excuse me as y minus y start at 2, so here we have again L by G, so L by G q, this q comes of the integrations and then we substitute the limits and go back and use my previous expressions for operating curves to obtain y minus y star at 1 and y minus y star at 2 and this will also be equal to then y 1 minus y 2 L by G q, again you go back and substitute the previous equation from the operating lines then we have y minus y star at 1, it is a simple mathematics as in exercise you just try this y minus y star at 1 and 2 over l n, y minus t star at 1 over y minus y star at 2.

we have a simple expressions for a very special case, when the equilibrium curve is linear and we have the dilute solutions y 1 minus y 2 over y minus y star logarithmic average, so that will logarithmic average between 1 and 2. So, this is expressions who one can obtained analytically for number of transfer units. Height of a transfer units is H t o G equals G prime over capital K y a, so this is your overall mass transfer coefficients. So, we have expression for N t o G and H t o G in this special case Z product of the 2, this will become G prime K y a into N t o G, y 1 minus y 2 over y minus y star m between 1 and 2. Sometimes the same equation is also rearranged to obtain this G 1 prime y 1 minus y 2.

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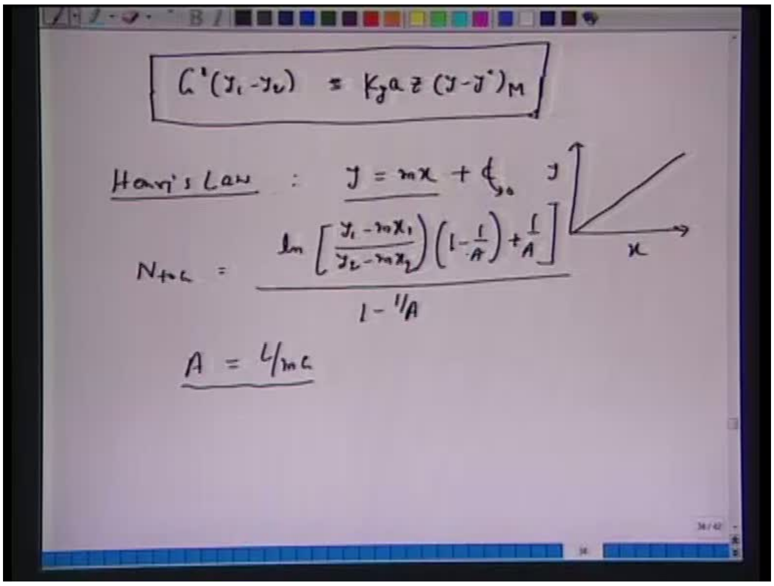

$$\boxed{G'(y_1 - y_2) = K_y a z (y - y^*)_M}$$

Henri's Law : $y = mx + \cancel{c}_{=0}$

$$N_{toG} = \frac{\ln\left[\left(\frac{y_1 - mx_1}{y_2 - mx_2}\right)\left(1 - \frac{1}{A}\right) + \frac{1}{A}\right]}{1 - 1/A}$$

$A = L/mG$

So, how much amount of sulphur dioxide the impurity is removed, this also equals capital K y a, Z y minus y star m. So, this also very frequently encounters in this type of expressions for a very, very special case, where we have this equilibrium curve being linear and we have this dilute solutions. There is another very special case that, if we follow Henry's law. If we have Henry's law and linear that means we have y equal to m x, so c being zero, so if we have the equilibrium curve like. This also very you know; when the intercept is very small or at very low concentration, we have very small mole fractions in the gas in the gas phase then we can write the equilibrium curve as y equal to m x.

In that case, N t o G can be shown to be obtain as a big expressions y 1 minus m x 2, so m is a slope of this equilibrium curve, y 2 minus m, though we have x 2 and here we have excuse me this should be m x 1, 1 minus 1 over A plus 1 over A over 1 minus 1 over A and A should be familiar at A is L by m g absorption constant. This is not the first time you are using this N t o G, if you recall in our previous first two to three lectures when we talked about the cascades in series or the devices in series, we said that one can obtain the expression analytically in that case also we had this similar expressions for number of devices or number of a stages in series required for certain rectifications. So it is a familiar expression and there also we defined this quantity A.

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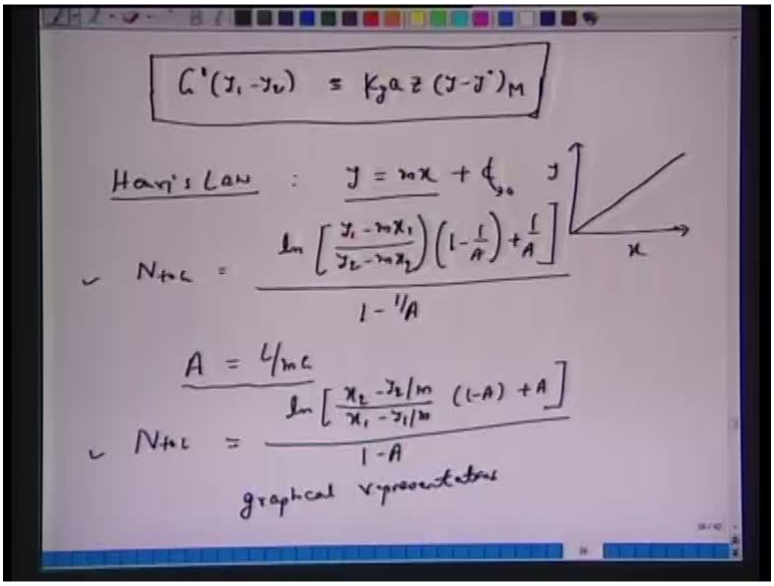

$$\boxed{G'(y_1 - y_2) = K_y a z (y - y^*)_M}$$

Henry's Law : $y = mx + c_0$

✓ $$N_{tOG} = \frac{\ln\left[\left(\frac{y_1 - mx_1}{y_2 - mx_2}\right)\left(1 - \frac{1}{A}\right) + \frac{1}{A}\right]}{1 - 1/A}$$

$$A = L/mG$$

✓ $$N_{tOL} = \frac{\ln\left[\frac{x_2 - y_2/m}{x_1 - y_1/m}(1 - A) + A\right]}{1 - A}$$

graphical representation

Similarly, for the liquid phase N t o G, if we write N T O L, one can show you should obtain L n, x 2, y 1 over m, x 1 minus y 1 over m, 1 minus A plus A, so we correct here this is x 2 minus y 2 over m, 1 minus A plus A over 1 minus A and both of the expressions in the literature or the textbook you will find there is a graphical representations. So, you can use this analytical expression or you can use the graphs directory. So, this is what we have as a theory for today's lecture or last two lectures, if you combine to obtain the height of a column given the operating conditions. So, very simple case given a gas flow rates, we know what is the composition of this gas at inlet to do this we have been given a solvent.

We know the composition of the solvent and we have been asked to find out the height 1, diameter 2 and the liquid flow rates. So, if you recall already we have addressed how to obtain the liquid flow rates, liquid flow rates comes from the minimum solvent requirement and then we take 1.5 times as in operating conditions. So, once we know the gas flow rate, we know the liquid flow rates, we know the two compositions one can obtained all y 1, y 2, x 1 and x 2, but we should also go back and check the hydrodynamics. In the sense that, since we have a counter current flow of liquid and gas they should not be loading and the flooding.

So, we have supposed to go back and use the classical that Eckerd plot or the Pickford plot for packing or the loading and flooding in the packing's, that will give us what should be there permitted gas flow rates per second per meter square cross-sectional area of this column, so from that we get G prime, G and G primes gives us the diameter of the column and from there we can get gives us the cross-sectional area of the column and from that we get the diameter of the column. So, the height of the column is now the only quantity left. We know G, we know L, we know all boundaries y 1, y 2, x 1, x 2, and we know the diameter of the column, so that we know the velocity. Once we know the velocity, we can obtain mass transfer coefficients.

If you recall that given the velocity, we know the Reynolds number, based on the Reynolds number, we can obtain Sherwood number and the Sherwood number will give us what is the mass transfer coefficient in the gas phase or in the liquid phase, equilibrium we have m, so we can find out also the overall mass transfer coefficients. So, we take this example to determine what is the height of this column based on the number of transfer units and the height of the transfer units.

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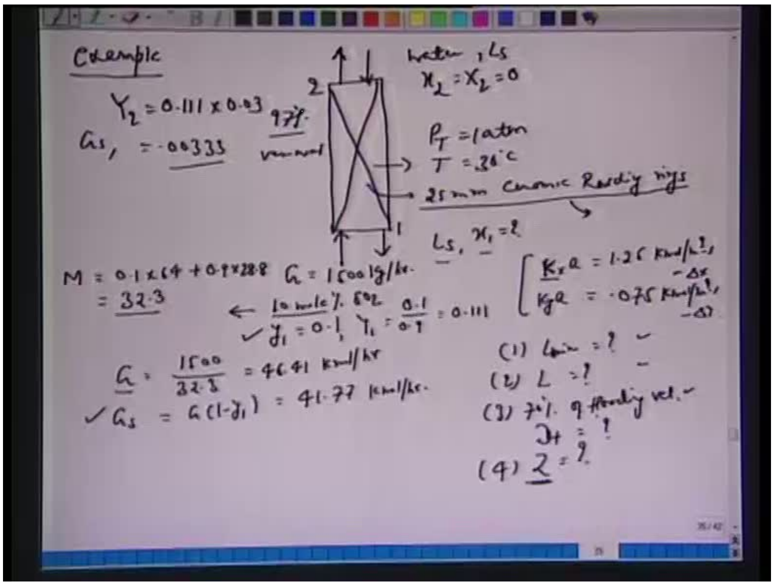

Example

$Y_2 = 0.111 \times 0.03$ 97% removal

G_s, $= .00333$

water, L_s

$x_2 = X_2 = 0$

$P_T = 1$ atm

$T = 30°C$

25 mm Ceramic Raschig rings

L_s, $x_1 = ?$

$M = 0.1 \times 64 + 0.9 \times 28.8$
$= 32.3$

$G = 1500$ kg/hr.

10 mole % SO_2

✓ $y_1 = 0.1$, $Y_1 = \frac{0.1}{0.9} = 0.111$

$G = \frac{1500}{32.3} = 46.41$ kmol/hr

✓ $G_s = G(1-y_1) = 41.77$ kmol/hr.

$K_x a = 1.25$ kmol/h^2, Δx

$K_y a = .075$ kmol/h^2, Δy

(1) $L_{min} = ?$

(2) $L = ?$

(3) 70% of flooding vel.
$D_t = ?$

(4) $Z = ?$

Let us to take this simple example to do the calculations. We have absorption column and we start with the similar approach or the similar type of problems, where this flow rate of the sulphur dioxide or total flue gases is given to us 1500 kg per hour, this contains 10 mole percent of sulphur dioxide, this should immediately we should write y 1 equal to 0.1, capital Y 1 equal to 0.1 divided by 0.9 to obtain 0.111. Since this 10 mole percent sulphur dioxide in air, we should be able to obtain molecular weight as 0.1 into 64 plus 0.9 into 28.8 for air to obtain the molecular weight or average molecular weight of this flue gas 30. 32.3. So, that we can obtain this G in kilomoles 1500 divided by 32.3 molecular weight equals 46.41 kilomole per hour and once we know this G, we can obtain G solid free basis solvent-free basis as G 1 minus y 1.

This is our one inlet here to obtain 41.77 kilomoles per hour, so we know G s, we know Y 1 and now we have been told that 97 percent of the sulphur dioxide is removed. So, 97 percent removal, once we know 97 percent removal, we have this, this end is 2, we obtain capital Y 2 as 0.111 into 0.03, so we are removing 97 percent 3 percent is left we have 0.00333. So, we know y 2, we know G s, G s will remain the same. Now, we have been given a solvent, which is water; pure water, so we have x 2 equals to capital X 2 equal to 0. So, there is no sulphur dioxide in this pure solvents and we have the exit concentrations where we have this L S, L S will remain the same x 1 becomes unknown quantities, so L S and x 1 are unknown quantities.

We have the packing's, it is a very standard type problems, which we addressed earlier also P T equal to given 1 atmosphere temperature is given 30 degree centigrade and it is packed with 25 millimeter of ceramic raschig rings. So, as soon as we see this 25 millimeter ceramic raschig rings, we can go to that table and we can get the different information we wanted for this packing factor, which we require to do this hydrodynamic calculations. This is also given to us that mass transfer coefficient K x A is 1.25 kilomole per cubic meter per second per del X, so notice this K x individual mass transfer coefficient based on the gas film is K x A 1.25 kilometer moles per cubic meter per second per del X.

So, check it is consistent with the definitions of mass transfer coefficients units and K Y is given as 0.75, this for the liquid phase, this for the gas phase, kilomole per cubic meter per second per del Y. So, this is given to us and we have been asked very typical questions what is number 1, calculate L mean minimum amount of solvent require, calculate L, which is 1.5 times the minimum solvent require our operating condition is at 70 percent of flooding velocity, based on this determine the diameter of the column and the last but not the list which we are going to decide and is going to calculate here determine the height of this column.

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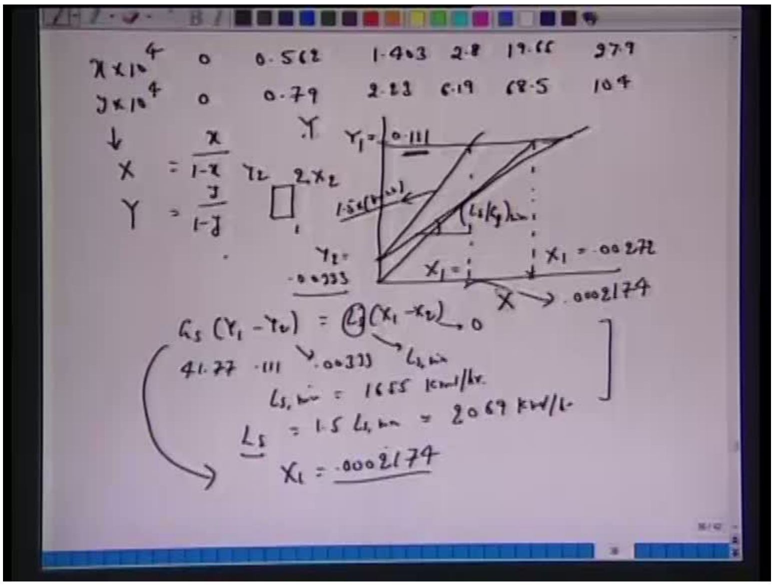

$x \times 10^4$	0	0.562	1.403	2.8	19.66	97.9
$y \times 10^4$	0	0.79	2.23	6.19	68.5	104

$X = \frac{x}{1-x}$

$Y = \frac{y}{1-y}$

$G_s(Y_1 - Y_2) = L_s(X_1 - X_2)$

41.77 .111 .00333 $L_{s,min}$

$L_{s,min} = 1655$ Kmol/hr.

$L_s = 1.5\,L_{s,min} = 2069$ Kmol/hr

$X_1 = .0002174$

First three already we have answered in our previous lecture. So, we will go very quickly here and then we have also been given this table to calculate; to draw this equilibrium curve, so this is thermodynamic data mole fraction 000.562, 0.79, 1.403, we have 2.23, 2.8, we have 6.19, 19.65, we have 68.5 then we have 27.9 we have 104. So, this x in 10 to power 4, all it means, I leave this as exercise we calculate capital X and capital Y, as x over 1 minus x, y as y over 1 minus Y and based on this, we should be able to draw this curve equilibrium curve x and y and if you it draw carefully, we will see that there is some convex down here, so there is some possibility of pinch occurring somewhere here, so you have to be very, very careful when you draw this curve here.

So, let us to mark the points here, we have been given 1 and 2, these was all column at location 1 and 2. We knew x 2, pure solvent and we knew y 2, so we can immediately mark this point as 0 for the solvents and we had this y 2 given here 0.00333. Y 1 we know this also given to us, y 1 as 0.111, so be careful when we plot not necessarily we have to plot from 0 to 1 for larger resolutions we should work only between the two limits point 0.00333 and 0.111. Now, if we realize there is a pinch here, we can draw this curve as a tangent so wherever it makes a tangent from there, we can get either X 1 or we can take the slope as L s by G s mean, so whichever way you think is comfortable you find the slope and then take 1.5 times, the slope would be 1.5 times the minimum or you can write down the expression for this operating curve and then you can obtained L s by G s operating curve, so either way we should be able to work.

So, if you write down the equations for operating curves we have G s, Y 1 minus Y 2 equals L s, X 1 minus X 2. So, we know these quantities 41.77, Y 1 we know 0.11, Y 2 we know 0.00333, L S mean we have to determine based on X 1, so this X 1 based on this tangent where it makes tangent will turn out to be 0.00272, so if we look at very carefully this is point 0.00272 and X 2 is of course 0. So, based on this we are can obtain L S mean as 1655 kilo mole per hour, that means operating curve L S is 1.5 times L S mean, to make it 2069 kilomole per hour. So, idea of doing this exercise is either you write down the expressions or directly from here, if you know the slope take 1.5 times a slope, obtain this curve and you can get X 1 operating, which will we can show that this quantity will be point 0.0002174.

So, either again you can go back and use this expressions knowing this putting the new values of L S to obtain this X 1, as points 0.0002174. So, the idea is that either use the graph to obtain this X 1 or you can go back and put the values of L S to obtain this X 1 quantity, so you should be familiar, we did in the last example earlier case also that either way graphical way or the equation will give the same results. So, these are first part of your question given L mean, we have determine L mean minimum amount of solvent require based on this driving force being 0, wherever it makes a tangent based on that we got obtain one 1.5 operating curves, we got the new values of X 1, so we have marked our all over boundaries.

The next is we have to go to hydrodynamics and see there is no flooding. There is no loading or flooding here and it is given that we have to operate at 70 percent of the operating curves about the flooding conditions, from that information we should be able to what is a cross-sectional area of the column required to avoid this flooding. So, that will give us G prime kg per second per meter square cross-sectional area and from that we will get the cross-sectional area and the diameter of the column.

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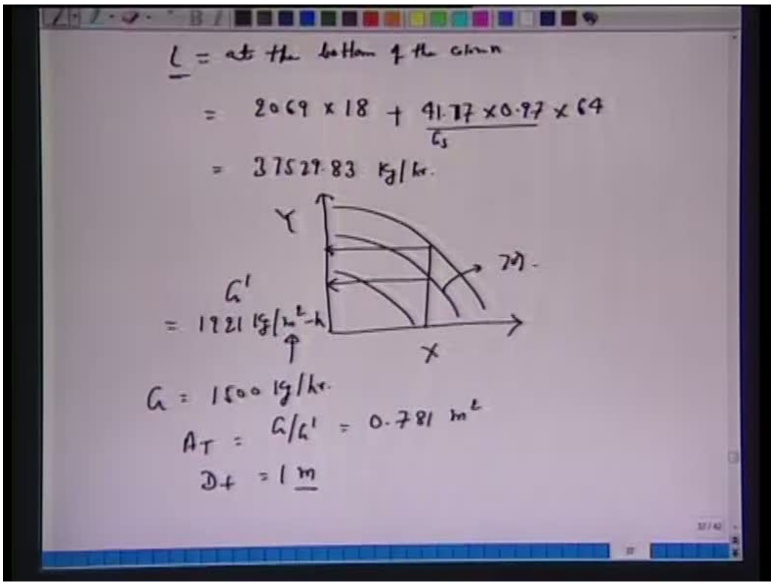

L = at the bottom of the column

$= 2069 \times 18 + \frac{41.77 \times 0.97}{G_s} \times 64$

$= 37529.83$ kg/hr.

$G' = 1921$ kg/m^2-h

$G = 1500$ kg/hr.

$A_T = G/G' = 0.781$ m^2

$D_T = 1$ m

Let us quickly do this exercise here. Now, if you recall in that plot, we have to suppose to get L S by G s. So, first get L at the bottom of the column, why this also we have discuss earlier, that the flow rate of the liquid is a maximum at the bottom, so the calculations to be more conservative site, we should do at the bottom of the column. So, at the bottom of the column, we have two 2069 kilomoles and then we have 18 water flow rate kg per hour, so this was the solvent 2069, so 2069 plus 18 kg per hour, plus we have sulphur dioxide in this, so how much is amount of sulphur dioxide, well we know the G s 4.0, 41.477 that is our G s, multiplied by 0.97, because 97 percent is removed, so whatever is removed it gets into this water face.

So, this is a amount of sulphur dioxide, which has gone into this water face into 64 molecular weight of sulphur dioxide, so this will be 37529.83 kg per hour of liquid flow rate, maximum flow rate which we have the liquids. So, now we can go back and draw this again very quickly. We should recall this curve for loading and flooding where you had certain quantities on the X, certain quantities in the Y, we have supposed to mark this curve here, go to this flooding that will give you flooding conditions, you operate on 70 percent of this pressure drop. So, when you work on the 70 percent of this quantity, you will get G prime from here. So, all of this I leave it as an exercise, already we have done this in the previous lecture.

This will give us G prime 1921 kg per meter square per hour, so look at this now we are getting this kg per meter square per hour. We know this G total gas flow rate as 1500 kg per hour. So, we know G we know G prime here, this will give us cross-sectional area, as G over G prime and this will give us 0.781 meter square from this, we get the diameter of the column as 1 meter. So far minimum amount of solvent, operating liquid flow rates, operating conditions, the boundaries and we got this diameter of this column to avoid this loading and flooding 70 percent of this business;70 percent of this flooding condition and now we start this very quickly. We do this height of the columns based on the number of transfer units and the height of a transfer unit.

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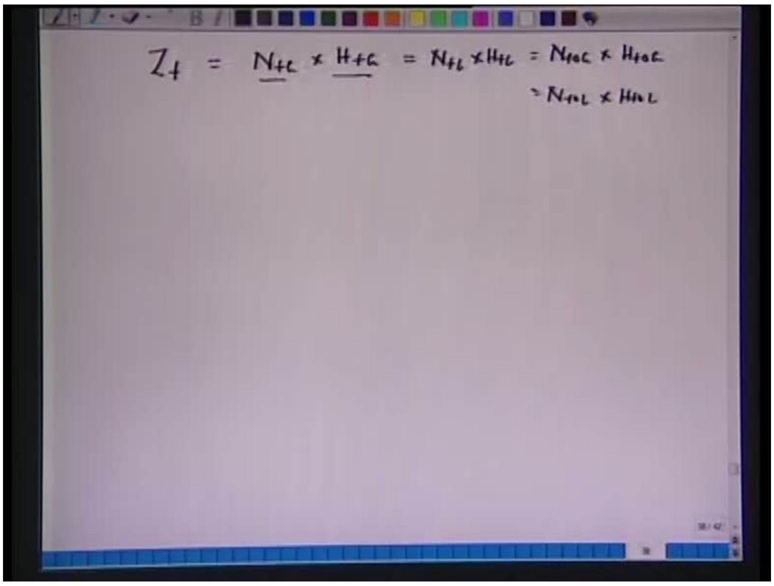

$$Z_t = \underline{N_{tG}} \times \underline{H_{tG}} = N_{tL} \times H_{tL} = N_{toG} \times H_{toG}$$
$$= N_{toL} \times H_{toL}$$

Again, we start from here Z t is N t G multiplied by H t G, this will also be equal to N t L multiplied by H t L, one can also work on overall transfer units are N t o G then we choose as S t o G, one can also work on N t o L multiplied by H t o L. So, they are all four different ways of writing this, height of a column or number of transfer units or height of transfer units. It is up to us, we have careful, you read the problem correctly, what are the quantities which are given to us, because you have to calculate you have to do these integrations for N t G and you have to calculate the height of a transfer unit based on this mass transfer coefficient.

In principle, each any of the four equations will work and should give you the almost approximately the same result with in this numerical calculations or numerical air. So, here if we recall the individual mass transfer coefficient for the gas phase and the liquid phase is given to us, so we should make use of and we should work on this N t G and H t g. There is no one can still work on N t o G and H t o G, but the compression will be slightly more cumbersome.

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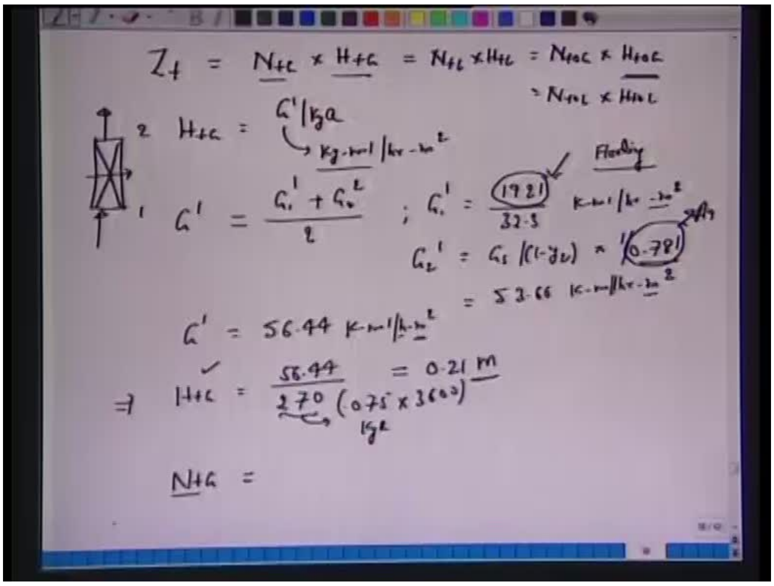

$Z_t = N_{tG} \times H_{tG} = N_{tL} \times H_{tL} = N_{toG} \times H_{toG}$

$= N_{toL} \times H_{toL}$

$H_{tG} = G'/K_y a$

kg-mol/hr-m^2

Flooding

$G' = \frac{G_1' + G_2'}{2}$; $G_1' = \frac{1921}{32.5}$ k-mol/hr-m^2

$G_2' = G_s/(1-y_2) \times 1/0.781$

$= 53.66$ k-mol/hr-m^2

$G' = 56.44$ k-mol/hr-m^2

$\Rightarrow H_{tG} = \frac{56.44}{270\,(0.75 \times 3600)} = 0.21$ m

$K_y a$

$N_{tG} =$

First is the very simplest H t G, which we know G prime K y a. This G prime again be careful, this is kg mole, it is not kg of loading and flooding and graph, so this is kg mole hour per meter square, this is the place where generally we make a mistake here. This G prime varies, so the question again comes what G prime you should use in this calculations, because it is not G s, so as the gas goes through this passes with the packed bed column the flow rate of the gas this kg mole per hour per meter square, it changes as there is mass transfer from the gas phase to the liquid phase. So, as a very good design or optimum design one should work on the average at G 1 and G 2 at the 1 and 2 inlet and the outlet of this column.

So, we know G 1 prime, this is 1 this is 2, this quantity we know we have calculated earlier 1921 divide by the molecular weight to give us kilomole per hour per meter square. So, this is what we calculated from G prime from flooding conditions. So, this was the 70 percent of the flooding limit from where we got 1921 kg, so we divide by the molecular weight to make it kilomole per hour per meter square and G 2 prime is nothing, but what we have G s over 1 minus y 2, so this is solvent-flow rate, which remains constant 1 and 2, so we have G s over 1 minus 1.2 into 1 over 0.7812 give you the same quantities 53.66 kilomole per hour per meter square.

So, what is this 0.781, this is the cross-sectional area we got, so this was kilomole per hour divided by per meter square, because we know this quantity again, this is the cross-sectional area to make it; to give us kilo hour per meter square and kilo per hour per meter square at 1 and 2. From this you put simple calculations, this will give us 56. 44, as the average mass flow rate based on this m t cross of superficial or the cross-sectional area of this column, so we know S t G here, so we know this is your G prime. So, we know the G prime all we have to do is to substitute our expressions, which is G prime over mass transfer coefficients. So, remember now you have to go back and see what mass transfer coefficient was given to us, which is 270.

So, how do we get this 270, it is given 0.075 individual film mass transfer coefficients multiplied by 3600, because this is per hour and what is given the problem is per seconds, so we have multiplied this to obtain 270, this will give us 0.21 meter, so height of a transfer unit is 0.21, so that simplest quantity we have obtain. If you want to work on H t o G then remember we have to and if you want to work on this quantity, then we have to do some more calculations here, so we have to see what the problems given, so that our calculation is simpler here, so we obtain H t G now we can obtain N t G. So, now we have to calculate number of transfer units N t G based on this gas phase individual gas phase.

So again, here if you read the problems it is given that sulphur dioxide at the inlet is 1 percent, so generally we treat 1 percent as a dilute of very small concentrations, in which case we can make this approximation and we can neglect 1 minus y logarithmic average.

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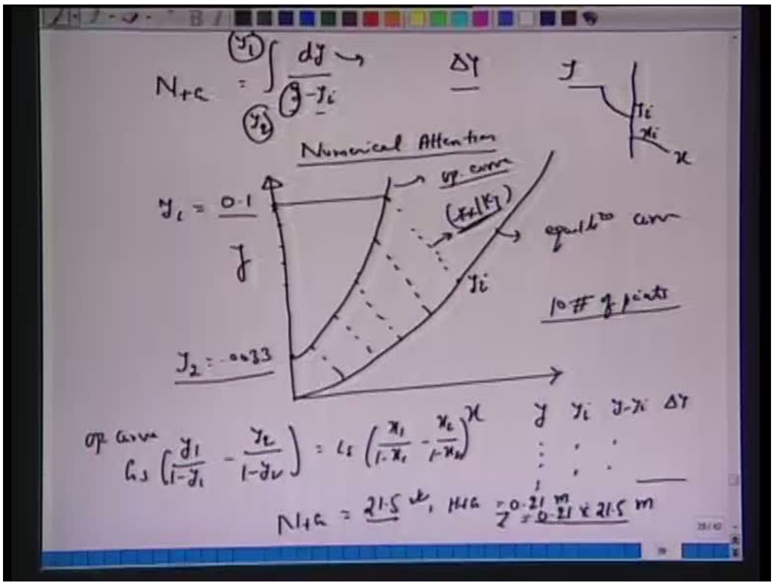

So, we write down this N t G expressions simplified form of N t G as dy over y minus y i, y 2 to y 1 so this what we have suppose to evaluate then we can obtain the height of the column Z here. So, this integral is now between y and y i, so this is the place where we requires numerical integrations, so you have to pay attention here how do we calculate this quantity, the best would be to do this graphically. So, we have this equilibrium curve y and x, so now we are working on a small x and small y. This is the original curve, equilibrium curve which we can for example we can plot like this. Now, y minus y i that means we have to obtain operating curve; we have to draw the operating curve.

So, what was the operating curve, operating curve is G s, capital Y 1 minus capital 1 or small y 1 over 1 minus y 1 minus y 2 over 1 minus y 2 equals L s, x 1, 1 minus x 1 minus x 2 over 1 minus x 2. So, in general we can write, replace y 1, y 2 or x 1 x 2 with y and x, so if you do this you will see that equilibrium curve. Now it will not to be a straight line, because we are working on the small y and small x. So, this would be the equilibrium curve and this is the operating curve. Note neither this is linear or nor this is linear.

So, this is small x and this is y, we have plotted on this and we have to mark we have to integrate from y 2 to y 1, recall we had this y 2 as 0.0033, so after 97 percent removal we had 0.003 and here we have 10 percent of this inlet sulphur dioxide, so y 1 is given as 0.1, so we know the limit y 2 and y 1 dy, y minus y i. So, all we have to do is, we have to take several small units del y, so this is numerical integrations, we have to work on del y. So, if you start from here how do we get y i, well you have to take a slope of minus K x over K y. So, this was very first few lectures said that from the based on the driving force we can obtain this y i here, so this is the interfacial concentrations.

Given the bulk phase concentration what is the interfacial concentrations, recall this schematics here y to y i and x i to x, so x i and y i and we have y here, so we have; we can take the slope here to obtain this y i. Similarly, you take some other points here, so you take several data points to obtain all these slopes in principal should be parallel, because we assumed that mass transfer coefficient do not change along this length, so take as many as points here between 1 and 2 preferentially you should take at least 10 number of points and then you make a table of given y what is y i, y minus y i and of course you have del y, you make a write down 1, 2, 3 add all of these or perform this calculations to obtain N t G, number of transfer unit and you should be able to obtain this N t G as around 21.5.

So, there it was a problem in which we have addressed that we obtained number of transfer unit as 21.5, height of a transfer unit already we have calculated, so height of a transfer units and number of a transfer units which is 0.21 meter, so the total height of the column is 0.21 multiplied by 21.5 meter, so try to understand this that entire column is approximately divided. So, we are saying that entire absorption column is divided into 22 units 21.5 approximately as a conservative design, height of this column has been divided in 22 small, small units and each units we are having a certain degree of rectifications.

So, total rectification we wanted to starting from 1 percent 2.003 percents, so from 0.1 to 0.003 percent we achieved this in the small 22 of such units, each units we have this fraction of total rectifications and we required certain height to achieve this, so 22 units multiplied by height of 1 unit will you give us the height of the column. So, this example we have shown one minimum amount of solvent require, two operating curves operating line 1.5, so that we can mark the boundaries then we obtain the diameter of the column or the cross-sectional area of the column to avoid the flooding and now we know the height of the columns and height of the columns we have obtain or we have calculated based on this number of transfer units and height of a transfer units approach.

One can also since liquid mass transfer coefficient is also given to us, you must have noticed that in the beginning we said that both K y a and K x a are given. So, you are most welcome to work on the liquid phase number of transfer units or liquid phase over height of transfer units to obtain very close results. One can also work on overall mass transfer coefficients, since we know the slope of the equilibrium curve m, one can also in principle can work on overall mass transfer coefficient based on the liquid phase or on the gas phase, each of this should give the same results. So, as an exercise you can try each of these four ways of calculating number of transfer units. So this finishes our chapter on absorptions may be we will take couple of more examples in the next lecture to address some of the issues in the absorption columns. Thank you.