Mass Transfer Operations -I
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Lecture – 23
Design of packed column absorber based on the Overall Mass Transfer Coefficient

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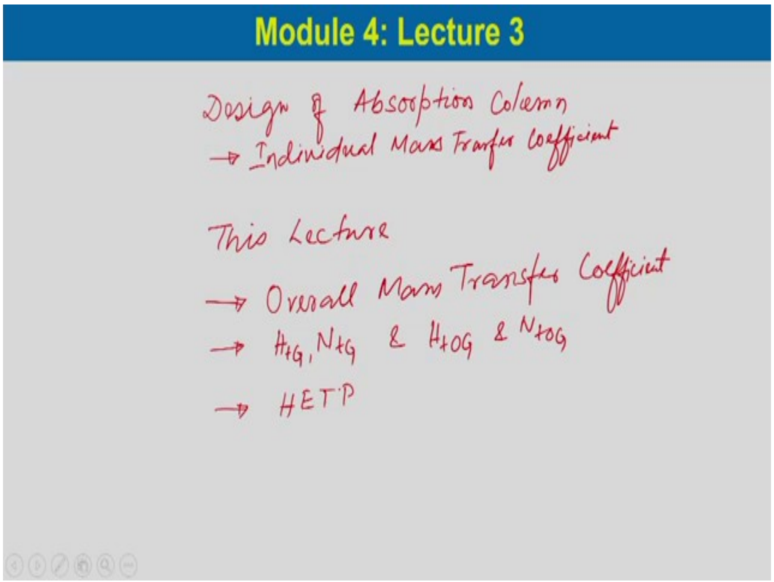

Welcome to the third lecture on Mass Transfer Operation, we are discussing module 4; in this module we are considering absorption. In our earlier lecture, we have considered design of absorption column and this is mostly based on the individual mass transfer coefficient method, individual mass transfer coefficient method. In this lecture we will mostly concentrate on the three important topic; one is design of packed tower based on overall mass transfer coefficient method, overall mass transfer coefficient.

So, the another method which we will consider is H t G and N t G method, also H t O G and N t O G method and how to design based on that. The third things which we will just briefly discuss on the H E T P method, height equivalent to a theoretical plate, H E T P method; so, we will know go detail one by one for the design of packed tower.

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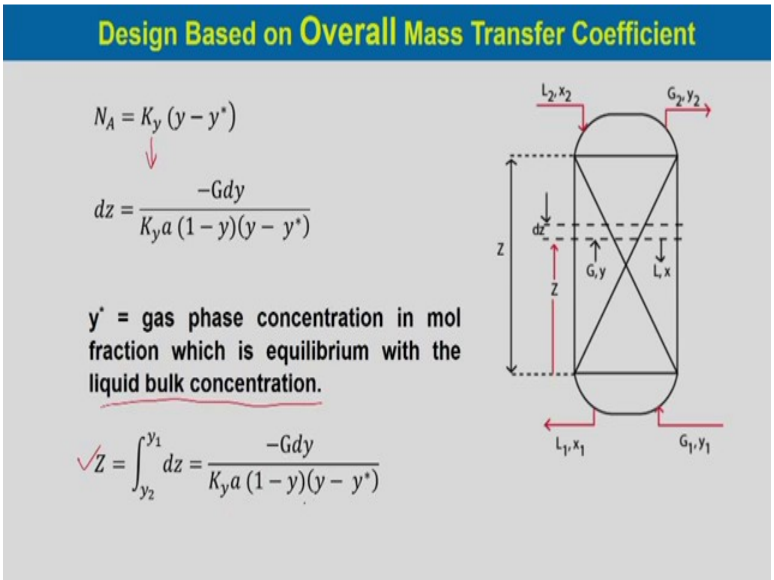

First, will consider design based on overall mass transfer coefficient method. Now, if we write, know the overall flux in a based on the overall mass transfer coefficient, we can write N A is equal to K y into y minus y star. So, here know capital K y is the mass transfer coefficient of the gas phase, based on the no mole fractions unit and y and minus y star is the mole fractions, in the gas phase and y star is the equilibrium mole fraction of the solute.

So, now the packing height d z would be equal to minus G dy by capital K y a 1 minus y into y minus y star. So, you can see the packed towers; which is given over here and you can see the inlet and outlet conditions the gas and liquid flow rate. Now, if we integrate this equation. So, you will get Z is equal to integral y 2 to y 1, dz would be equal to minus G dy divided by capital K y a into 1 minus y into y minus y star. This y star is the gas phase concentration in mole fraction, which is in equilibrium with the liquid bulk concentration. So, from these if we know all the data, we can just integrate and obtain the value of Z.

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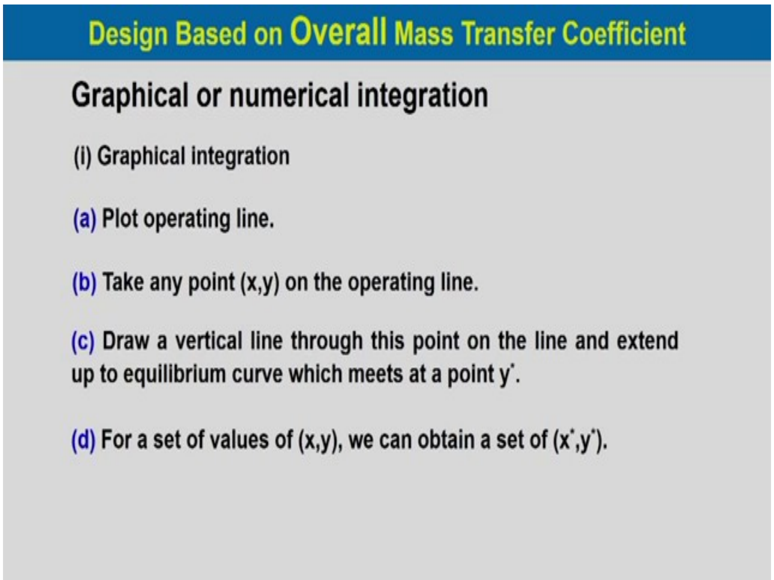

Now, this is generally done by graphical or numerical integration of the equations you have seen. For graphical integration if you do, we need to do plot, the operating line first, based on the data available and then take any point x y on the operating line, draw a vertical line through this point, on the line and extend up to the equilibrium curve, which meets at a point y star.

So, we have the equilibrium data for a particular system; you have the equilibrium curve. Now, with the data which are given, you can plot the operating line as we have done before; similar procedure has to be followed. Now, from any point in, on the operating line, if you just go vertically to and to the equilibrium curve, it meets at a point, which will be y star, the equilibrium values.

Now, for a set of values of x and y we can obtain value set of x star and y star. Now, we can do the graphical integration for that equation of Z and we can obtain the values of height of the packing materials required for a particular separation.

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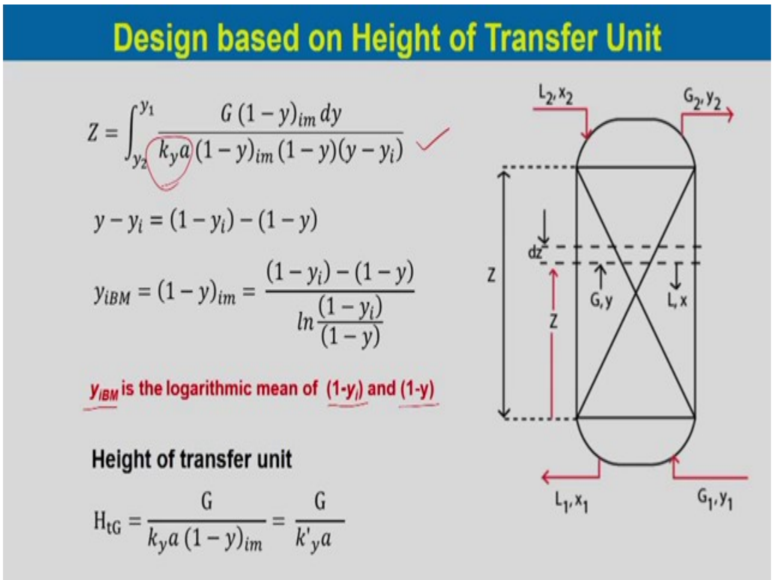

Now, we will discuss design based on height of transfer unit, H t G. So, Z you can see, we can write Z is equal to integral y 2 to y 1 G into 1 minus y i m d y divided by small k y a into 1 minus y i m into 1 minus y into y minus y i. So, this is the equations, we can write based on the individual or a mass transfer coefficient.

So now, y minus y i, we can write 1 minus y i minus 1 minus y. So, if we write y i B M would be equal to 1 minus y i m, which is equal to 1 minus y i minus 1 minus y divided by l n 1 minus y i by 1 minus y. So, basically y i B M or 1 minus y i m is basically the, know log mean concentration gradient or difference log mean concentration difference.

So, it is called logarithmic mean of 1 minus y i and 1 minus y. So, that is y i B M. Now, the height of transfer unit, which is defined is H t G. So, this part G by k y a into 1 minus y i m is called the height of transfer unit, based on the individual mass transfer coefficient. So, this term over here at the bottom, we can write as k dash y e. So, this is H t G, we can write as G by k y dash a.

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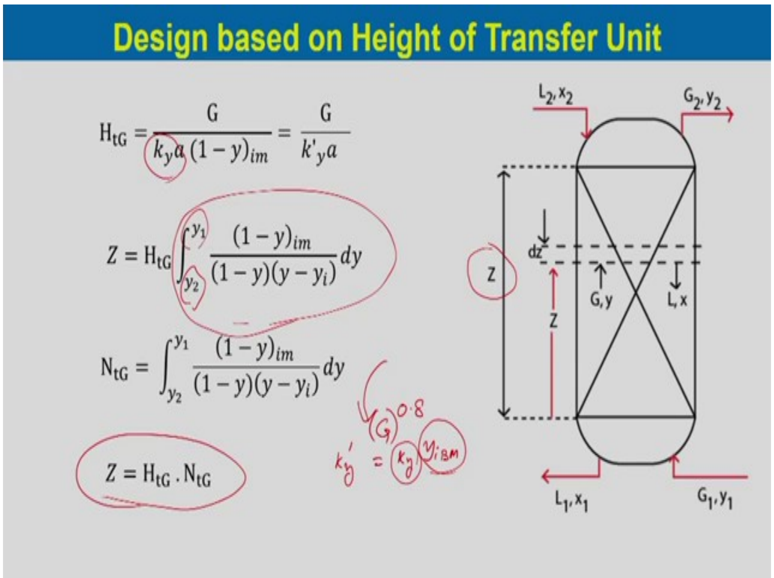

Now, the Z we can write H t G integral y 2 to y 1 1 minus y i m divided by 1 minus y into y minus y i d y. Now, this term over here is basically, represents a number this is number of transfer unit. So, this is y 2 to y 1, 1 minus y i m divided by 1 minus y into y minus y i d y.

So, this part is N t G. So, we can write no total height of the packing required would be equal to H t G into N t G; so, height of no packing tower, which is required for a particular separation. We can write in terms of height of transfer unit into the number of transfer unit. In general this G, the gas phase mass transfer coefficient k y, it varies with the no gas flow rate. So, gas phase mass transfer coefficient k y varies with G to the power 0.8 and also the colburn drew mass transfer coefficient that is k y dash this is called colburn drew mass transfer coefficient which is equal to k y y i B M. It remains independent under the conditions, but this k y depends on the concentration gradients or log mean concentration difference which is y i B M, but k y dash remains fairly independent throughout the driving force.

So, as a result we can see that G by k y a into 1 minus y i m, this term that is H t G, remains fairly constant throughout the tower, throughout the bed. Although the gas flow rate G varies. So, H t G is fairly constant and that is why it is called height of transfer unit based on individual mass transfer coefficient or the height of an individual gas phase transfer unit. So, that is why it is denoted as H t G.

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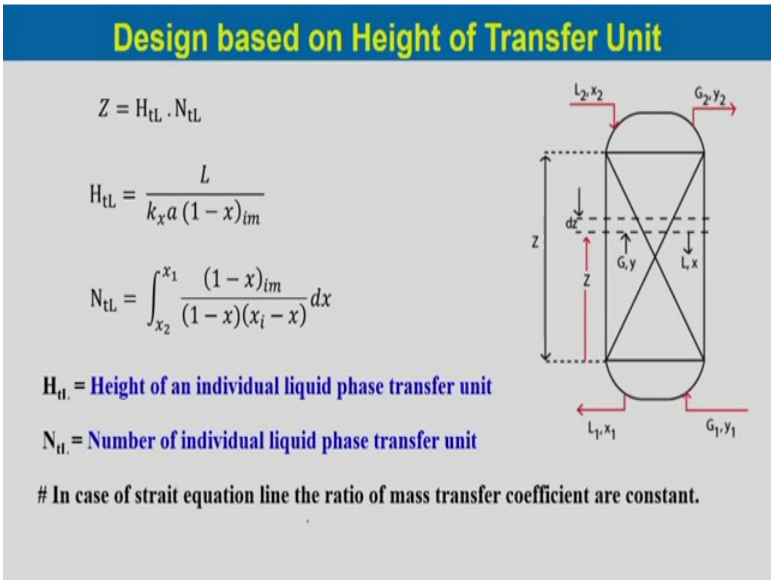

Now, as in the case of gas phase height of transfer unit, we have considered based on the gas phase mass transfer coefficient, we can also write in terms of the or we can also calculate with respect to the liquid phase mass transfer coefficient, where we can write Z is equal to H t L into N t L. So, H t L is equal to L by small k x a into 1 minus x i m and so, N t L is equal to integral x 2 to x 1 1 minus x i m divided by 1 minus x into x i minus x dx.

So, H t L is the height of an individual gas phase transfer unit or simply called height of transfer unit and N t L is called number of individual liquid phase transfer unit. In case of straight equation line the ratio of mass transfer coefficient are constant.

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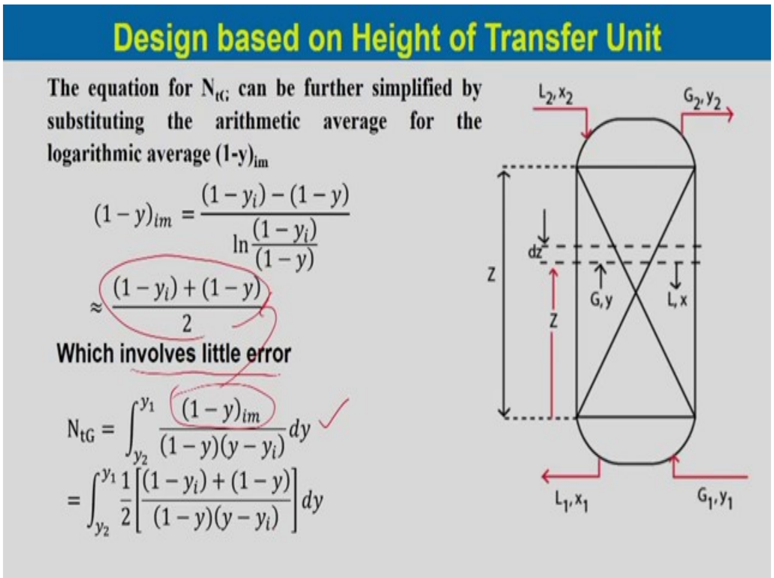

Now, this equation of N t G can be further simplified, substituting the logarithmic average for 1 minus y i m, 1 minus y i m, we can just simplify this logarithmic average, which is 1 minus y i minus 1 minus y divided by l n 1 minus y i divided by 1 minus y. We can simplify with the arithmetic average.

So, arithmetic average we can write 1 minus y i plus 1 minus y divided by 2. Now, if we just write down the equation of N t G so, this simplification which will help to solve our equation for the integration, if we use arithmetic average will involve very little error. If we substitute in the equation of N t G, then it will be integral y 2 to y 1 1 minus y i m divided by 1 minus y into y minus y i dy. So, in place of this, if we substitute this term; so it will be integral y 2 to y 1 half 1 minus y i plus 1 minus y divided by 1 minus y into y minus y i d y.

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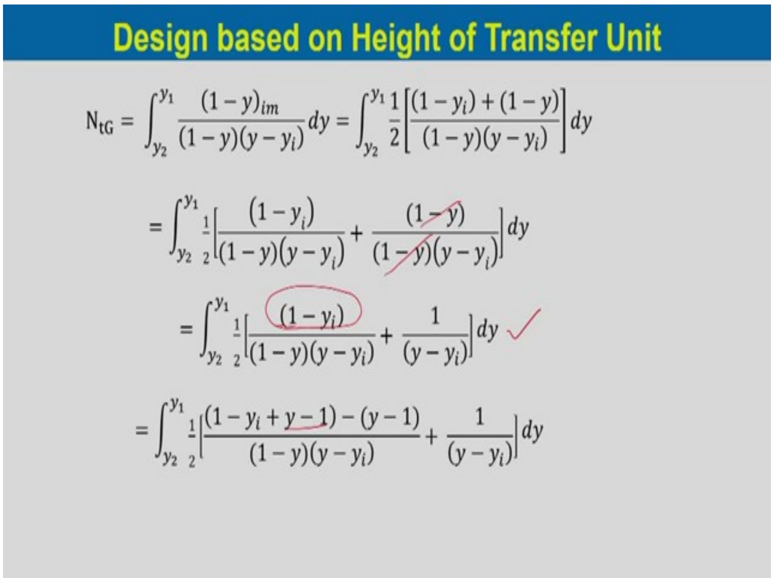

This we can and just further simplify by writing this two terms, dividing this into two terms and then if we divide with this two different part, then it will be 1 minus y i divided by 1 minus y into y minus y i plus 1 minus y divided by 1 minus y y minus y i d y. So, this essentially will cancelled out and we will have 1 minus y by 1 minus y y minus y i plus no 1 by y minus y i into dy. So, this is the equation and then this part, we can simplify by adding plus y and minus 1 and then we subtract the same quantity y minus 1 from this and this part remains same; so we would obtain this relation.

So, now this part will become y minus y i and so, this will cancelled know, we can write into part from this section, which we have written over here.

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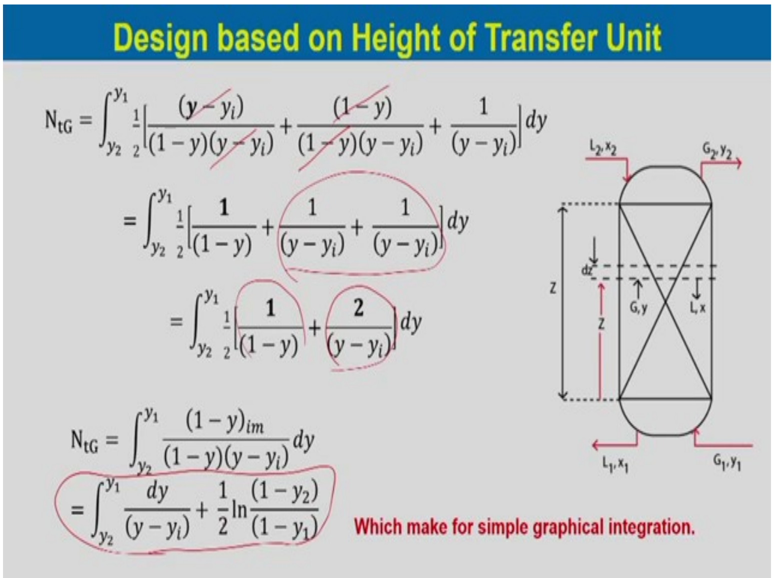

We have written in two part y minus y i divided by 1 minus y into y minus y i plus 1 minus y divided by 1 minus y into y minus y i plus 1 by y minus y i into dy. So, here know, this will cancelled out, so we will get half into integral y 2 to y 1 half into 1 by 1 minus y plus y 1 1 by y minus y i plus 1 by 1 y minus y i d y.

So, these two part will be 2 by y minus y i and this is another part, which is remains and now, if we just multiply with half both the sections so, we will obtain y 1 y by 2 into d y by y minus y i plus half into l n 1 minus y 2 by 1 minus y 1. So, this part we can integrate simply with the limit y 2 to y 1 and this part we have to integrate graphically. So, this makes simpler for graphical integration only by changing the logarithmic mean to the arithmetic mean and then with the mathematical manipulations. So, we can obtain this relation, which will be simpler for graphical integration.

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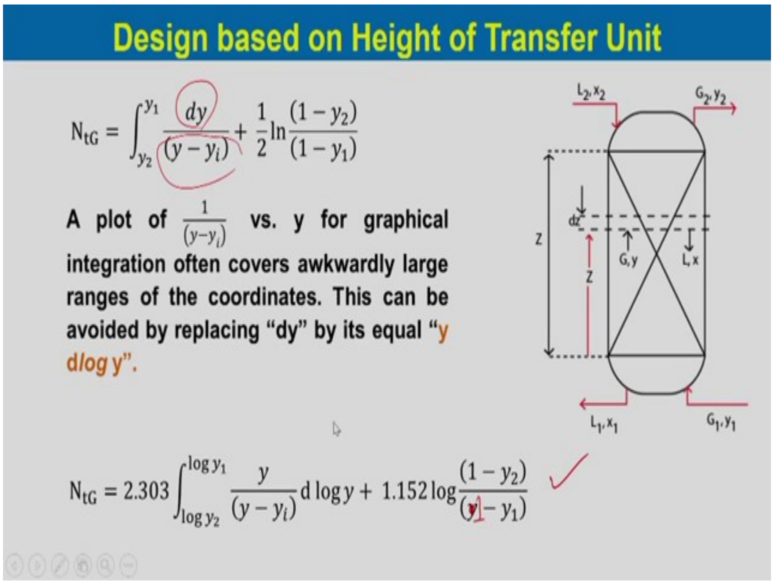

Now, sometimes it happens that, if we plot 1 by y minus y i, this part versus y for graphical integration. It often covers awkwardly large range of the coordinates.

So, this can be avoided by replacing dy by it's equal y d log y. So, if we just replace instead of dy with d log y then this will again help to know, do the graphical integration. So, which you will get N t G would be equal to 2.303 integral log 2 to log y 1 y by y minus y i d log y plus 1.152 log 1 minus y 2 divided by, this would be 1 1 minus y 1. So, this will help to do the graphical integration very simple.

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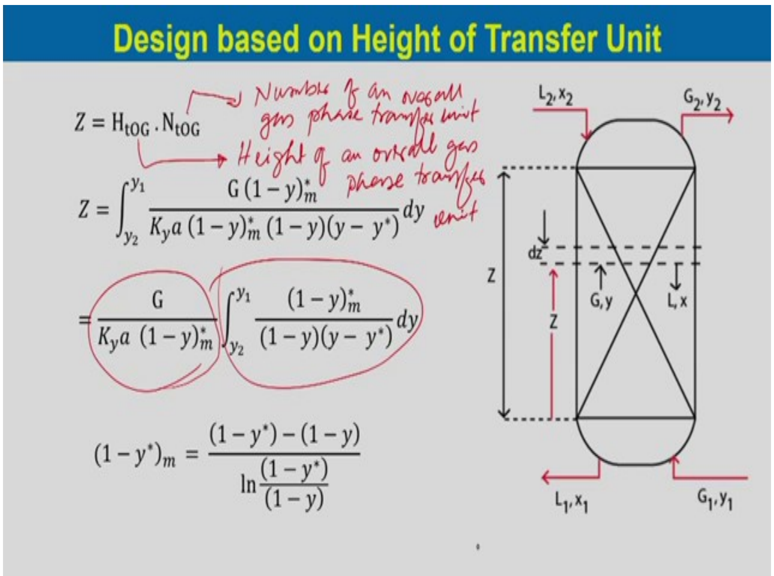

Now, instead of using the individual mass transfer coefficient that is small k y a or small k l a, we can also obtain the values of Z based on the overall gas phase transfer unit or overall height of transfer unit and number of overall transfer unit. So, this Z we can write integral y 2 to y 1 G into 1 minus y star m divided by K y a capital K y a 1 minus y star m into 1 minus y into y minus y star dy. So, if we write in this form, this part we can take it out G by capital K y a 1 minus y star m integral y 2 to y 1 1 minus y star m divided by 1 minus y y minus y star dy.

So, this part now, 1 minus y star m is basically the log mean concentration gradient, which is written in terms of the, you know equilibrium constant and the bulk concentration which is y star and y. So, this part is H t O G and this part is N t O G. So, H t O G is the height of an overall gas phase transfer unit. Similarly, N t O G is the number of an overall gas phase transfer unit.

This way we can calculate the height of the packing, required for a particular separation, knowing the values of the equilibrium constant and the bulk concentration. Now, let us take an example to calculate the height of know, packing required for a particular separation.

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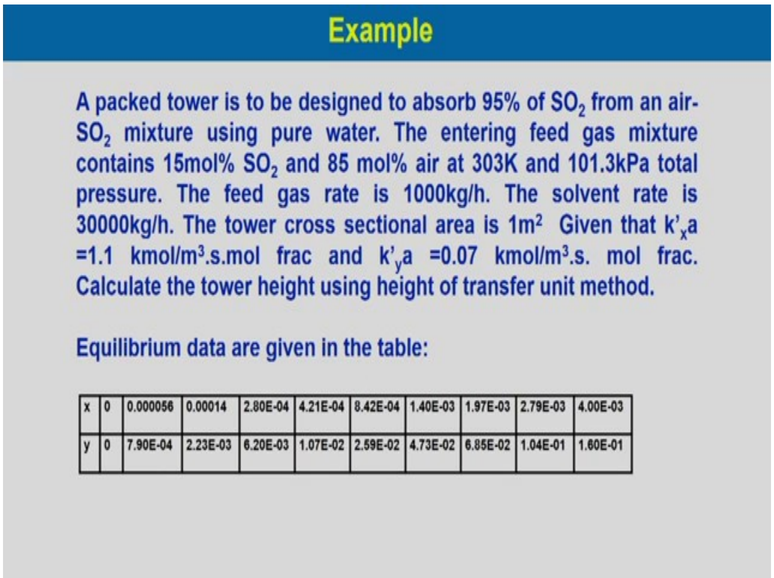

A packed tower is to be designed to absorb 95 percent of sulphur dioxide from an air sulphur dioxide mixture using pure water. The entering feed gas mixture contains 15 mol percent sulphur dioxide and 85 mole percent air at 303 Kelvin and 101.3 kilo Pascal total pressure. The feed gas rate is 1000 kg per hour, the solvent rate is 30000 kg per hour, the tower cross sectional area is 1 metre square.

Given that k x dash a is equal to 1.1 kilo mole per metre cube second mole fraction and k y dash a is equal to 0.07 kilo mole per metre cube second mole fraction. Now, we have to calculate the tower height using height of transfer unit method. These are the equilibrium data which are given. So, the similar problem we have solved in case of individual mass transfer coefficient method. Here, we will use the height of transfer unit method to calculate the tower height required.

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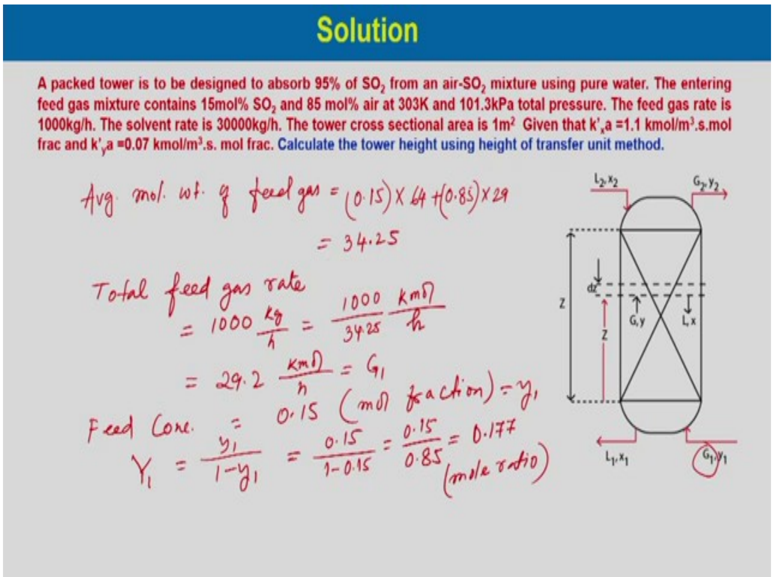

Now, as we have done before, we need to calculate the average molecular weight of the feed gas, which is equal to 0.15 that is 15 percent sulphur dioxide in the feed gas. Its molecular weight is 64 plus 85 percent air, which is 0.85 into it's molecular weight is 29. So, this will give 34.25; now, total feed gas rate, we can calculate total feed gas rate. The feed gas rate is given 1000 kg per hour, we need to convert into kilo mole per hour. So, this would be equal to know 1000 divided by the average molecular weight, which is 34.25. So, this is k mole, kilo mole per hour and which will be about 29.2 kilo mole per hour.

So, this is the gas flow rate at the inlet; that is G 1. So, this G 1 and then the feed concentration, which is in mole fraction unit is 0.15 mole fraction. So, we can calculate in mole ratio unit capital Y, which is equal to or capital Y 1 would be equal to small y 1 divided by 1 minus y 1. So, this is y 1 and if we substitute, it is 0.15 divided by 1 minus 0.15. So, it would be 0.15 divided by 0.85 and this would be 0.177 mole ratio unit.

So, we got in now, feed concentration both in mole fraction as well as in mole ratio unit is available with us. Now, we have to calculate the feed gas rate on solute free basis.

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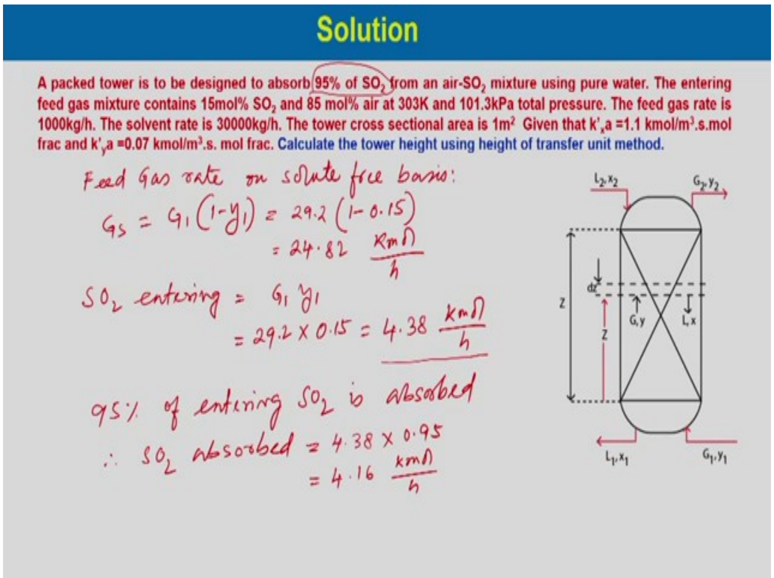

The feed gas rate on solute free basis is G s, which is equal to G 1 into 1 minus y 1. Now, if we substitute it is G 1 is 29.2 into 1 minus 0.15. So, this would be equal to 24.82 kilo mole per hour.

So, the sulphur dioxide, which is entering would be equal to G 1 y 1 and this is 29.2 into 0.15. So, this is know is about 4.38 kilo mole per hour. From this entering sulphur dioxide we have to absorb 95 percent. So, 95 percent of the sulphur dioxide has to be absorbed. So, 95 percent of entering sulphur dioxide is absorbed. Therefore, sulphur dioxide absorbed would be equal to 4.38 multiplied by 0.95, which would be equal to 4.16 kilo mole per hour. Since, we know the amount of sulphur dioxide entering and the amount of sulphur dioxide which is absorbed, we can now calculate the no, sulphur dioxide which is leaving.

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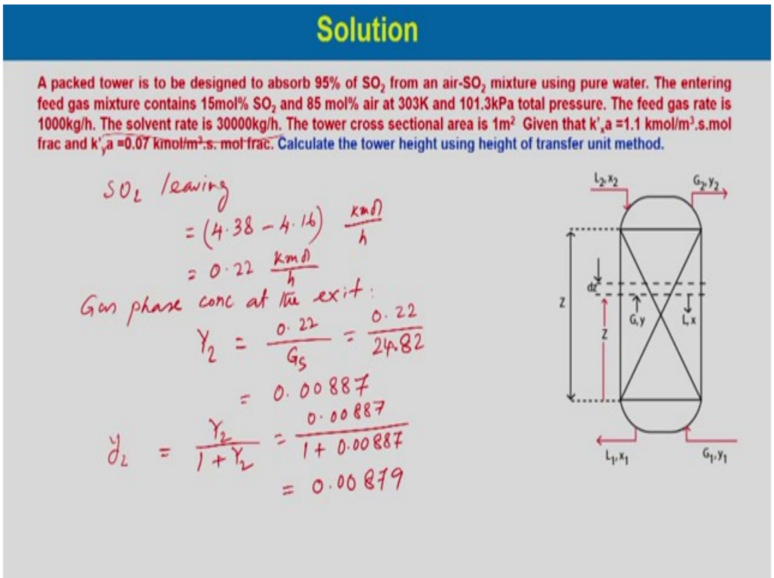

So, the sulphur dioxide leaving the tower would be equal to 4.38 minus 4.16 kilo mole per hour, which is equal to 0.22 kilo mole per hour. Now, we can calculate the gas phase concentration at the exit, gas phase concentration at the exit which is know capital Y 2 would be equal to 0.22 divided by G s. This is equal to 0.22 divided by 24.82 and this is 0.00887. Now, we can also calculate in know mole fraction unit y 2 would be equal to capital Y 2 divided by 1 plus capital Y 2, which is equal to 0.00887 divided by 1 plus 0.00887 which is equal to 0.00879.

We now calculate exit gas concentration and also we can calculate with the values of the liquid inlet, the flow rate of the liquid inlet is given that is the solvent rate is given.

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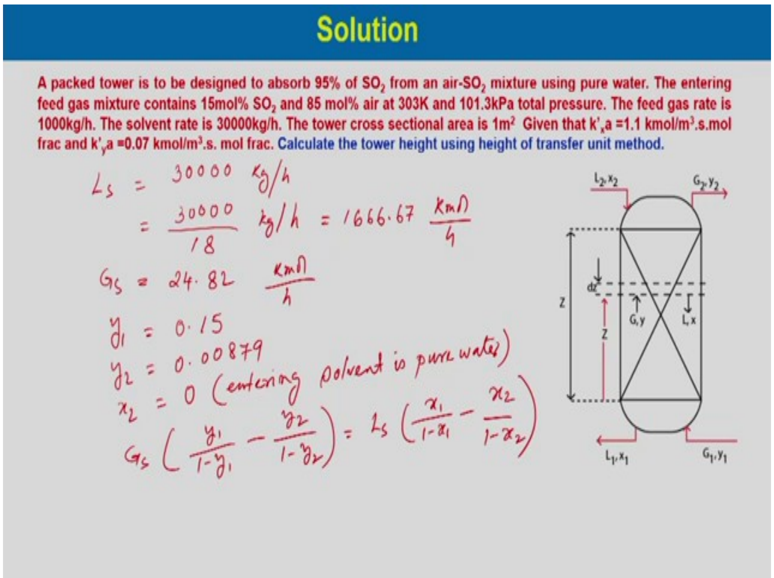

So, we can convert it to molar flow rate as L s would be equal to 30000 know kg per hour. So, we need to convert it to moles; so it is water. So, the molar flow rate would be 30000 divided by 18 kg per hour, which is equal to 166 6.67 kilo mole per hour. G s is known, we have calculated is 24.82 kilo mole per hour, y 1 is known is 0.15 y 2 is also known point 0.00879 and x 2 is know 0 as the know liquid solvent, which enters into the column is pure water.

So, entering solvent is pure water. So, the solute concentration is 0, so x 2 is 0. Now, if we just write the overall material balance equation that is G s into y 1 by 1 minus y 1 minus y 2 divided by 1 minus y 2 is equal to L s into x 1 divided by 1 minus x 1 minus x 2 divided by 1 minus x 2. So, if we substitute of values now, we can calculate the values of x 1.

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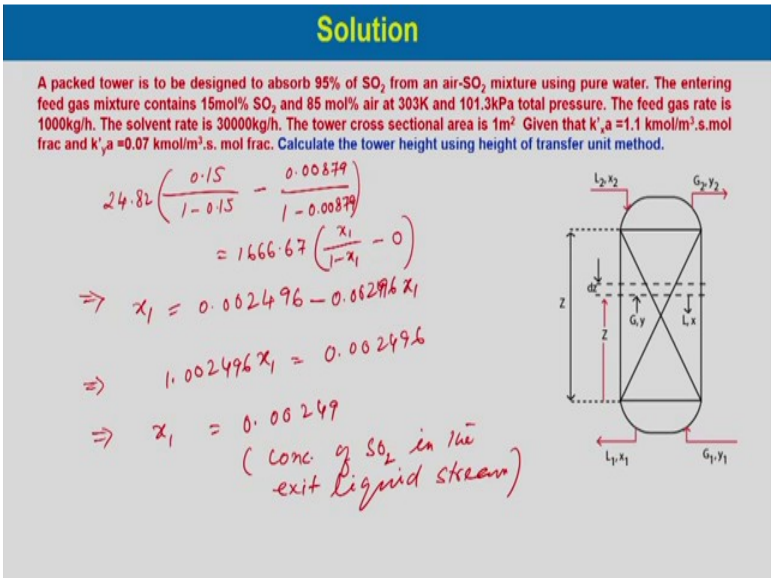

So, G s is 24.82 is no y 1 is 0.15 divided by 1 minus 0.15 minus y 2, we have calculated 0.00879 divided by 1 minus 0.00879 which would be equal to Ls. Ls is 1 triple 6 0.7 into x 1 by 1 minus x 1 minus 0 at x 2 is 0. So, this is 0. So, if we simplify this equation we can get x 1 would be equal to 0.002496 minus 0.002496 x 1.

This will give 1.002496 x 1 would be equal to 0.002496 and hence from here we can get x 1 would be equal to 0.00249. This is the concentration of sulphur dioxide in the exit liquid stream. So, now, we have all the data available with us, that is both the inlet composition and the outlet composition of the gas and liquid are known and all other parameters are known to us, we will now, no proceed with the design equations.

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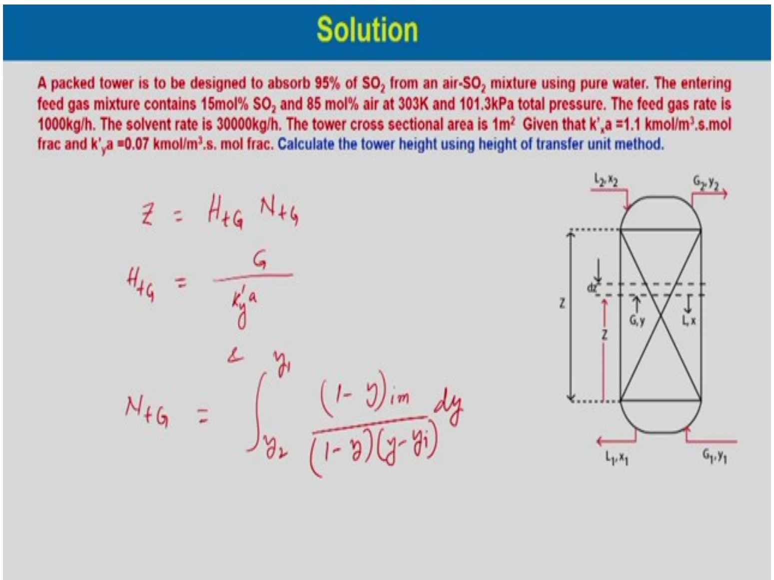

So, the design equation is Z is equal to H t G into N t G. H t G is equal to G divided by k y dash a and N t G is equal to integral y 2 to y 1 1 minus y i m divided by 1 minus y into y minus y i d y. These values are known and we have to find out the N t G and by the integration of this equation.

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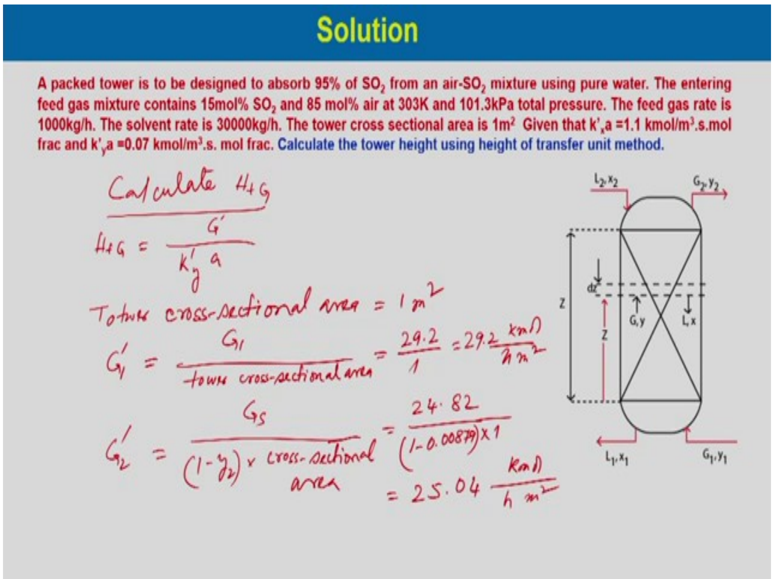

So, let us calculate H t G. H t G is equal to G by or G dash by k y dash a. Now, tower cross sectional area, this is equal to 1 metre square. So, G 1 dash would be G 1 divided by tower cross sectional area. So, this would be equal to 29.2 divided by 1, which is know 29.2 kilo mole per hour metre square.

G 2 dash we can calculate G s divided by 1 minus y 2 into the tower cross sectional area and this is 24.82 divided by 1 minus 0.00879 into 1; so, which is equal to 25.04 kilo mol per hour metre square.

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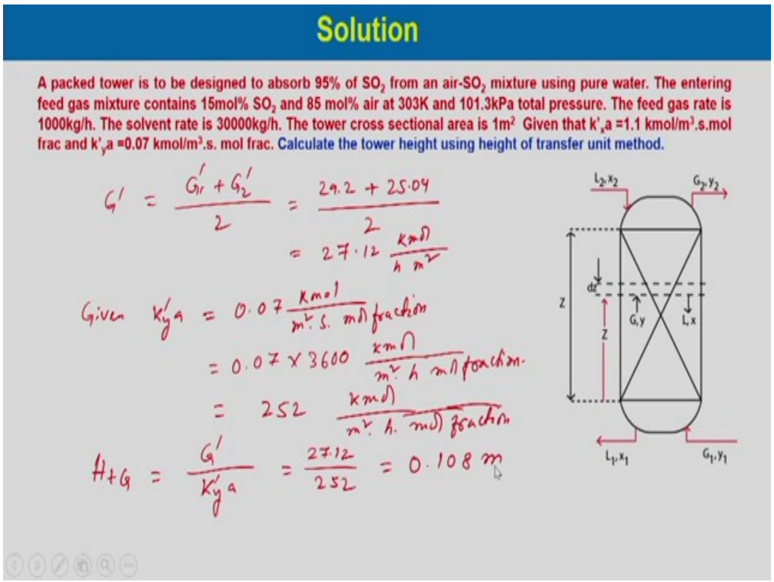

So, the if we take the average of G 1 dash and G 2 dash, we can obtain G dash would be equal to G 1 dash plus G 2 dash divided by 2, which is equal to 29.2 2 plus 25.04 divided by 2, which would be 27.12 kilo mole per hour metre square. Now, given the values of k y dash a is equal to 0.07 kilo mole per metre square second mole fraction. We can just multiply with the 3600 to get in terms of kilometre metre square hour. So, 0.07 into 3600 k mole per metre square hour mole fraction, which would be about 252 k mol per metre square hour mole fraction.

So, we can calculate H t G would be equal to G dash by k y dash a, which is equal to 27.12 divided by 252, which is about 0.108 metre.

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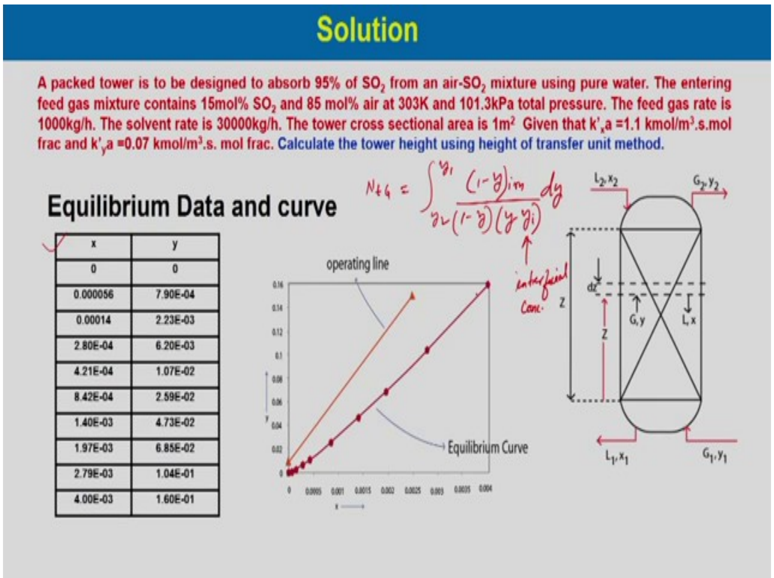

Now, we need to calculating N t G, we have to use the equation N t G is equal to integral y 2 to y 1 into 1 minus y i m divided by 1 minus y into y minus y i d y. So, the y i over here is the interfacial concentration. Now, you have to obtain this interfacial concentration from the data which are given. The equilibrium data are given, which is here in this table and we can plot the equilibrium curve and with the data given the terminal concentration, we can plot the operating line. Now, from this graph we can calculate the interfacial concentration. We will discuss this, how we can calculate the interfacial concentration.

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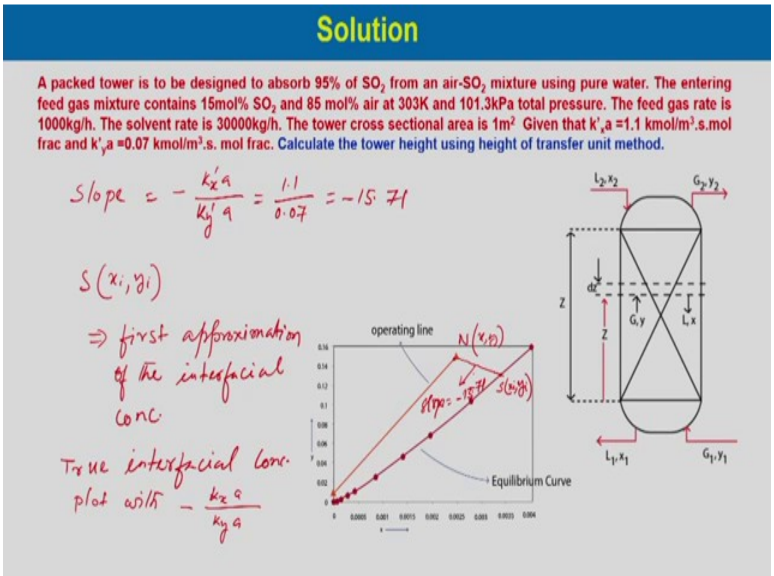

So, we can take the slope, slope is minus k x dash a divided by k y dash a. Now, if we substitute the values, which are given is 1.1 divided by 0.07. So, this would be equal to minus 15.71. Now, let us take a point somewhere over here, say point N with know x and y values and with the slope if we plot, we can get a know point over here, which is know say point S, which is on the equilibrium curve which is x i and y i. So, the S point as a S which we obtain with a point N is equal to x and y any values and with the slope. If we plot the slope of the curve is know minus 15.71. So, the x y we will meet you know x i and y i x i and y i, these are the interfacial concentration which it will give is the first approximation of the interfacial concentration.

Now, to obtain the true interfacial concentration, we have to plot with a slope to obtain true interfacial concentration. We need to plot with a, plot with minus k x a divided by k y a. So, now we have to calculate k x a by k y a from the values given.

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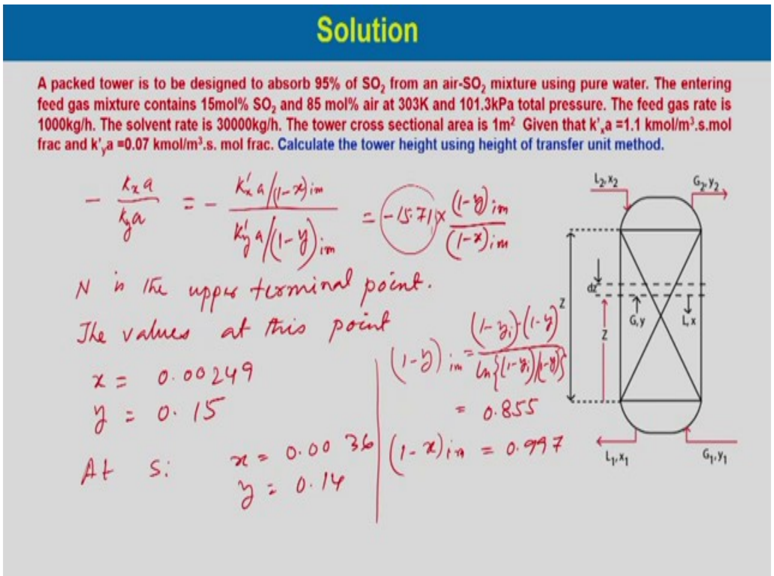

So, from the definition k x a divided by k y a would be equal to minus k x dash a divided by 1 minus x i m divided by k y dash a by 1 minus y i m, which would be equal to minus. So, the ratio of k x dash a by k y dash a is minus 15.7 1 multiplied by 1 minus y i m divided by 1 minus x i n, the n which we have considered in the earlier equation, the figure on the operating line is the upper terminal point.

The values which we obtained at this point is x is equal to 0.00249 and y is equal to 0.15. So, if we plot with that slope, slope of this one then we can get at s, the values know x is equal to 0.0036 and y is equal to 0.14. Now, this should be the starting point to calculate the true values.

So, here we calculate 1 minus y i m, if you substitute these values, this would be 1 minus y i into minus 1 minus y divided by l n 1 minus y i divided by 1 minus y. So, if we substitute these values from here; so, we will obtain 0.855. Similarly, 1 minus x i m, we can obtain substituting these values would be 0.997. Now, if we use this value over here and we can calculate this k x a by k y a.

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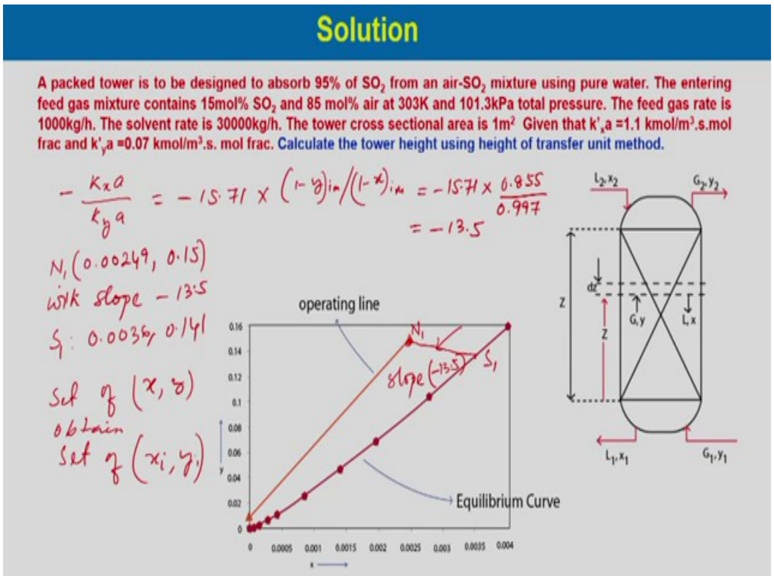

So, calculate minus k x a divided by k y a would be equal to minus 15.71 into 1 minus y i m divided by 1 minus x i m. So, if we substitute both the values, it is minus 15.71 multiplied by 0.855 divided by 0.997. So, this would be minus 13.5. Now, our know the point over here is N, which is over here is 0.00249 and 0.15. From this point with the slope minus 13.5, if we plot know we will obtain the true interfacial concentration at S. So, at S we have no say S 1 from N 1. We can get 0.0036 and 0.141.

So, we will get this is the slope with from N 1 to S 1 and with the slope minus 13.5. So, we can get a set of values, set of x y, we can get set of x i and y i the 2 interfacial concentration.

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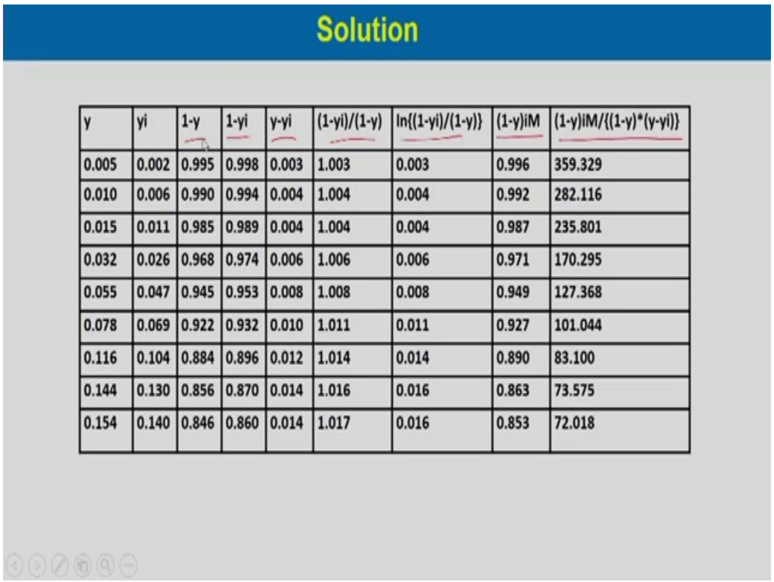

Solution

y	yi	1-y	1-yi	y-yi	(1-yi)/(1-y)	ln{(1-yi)/(1-y)}	(1-y)iM	(1-y)iM/{(1-y)*(y-yi)}
0.005	0.002	0.995	0.998	0.003	1.003	0.003	0.996	359.329
0.010	0.006	0.990	0.994	0.004	1.004	0.004	0.992	282.116
0.015	0.011	0.985	0.989	0.004	1.004	0.004	0.987	235.801
0.032	0.026	0.968	0.974	0.006	1.006	0.006	0.971	170.295
0.055	0.047	0.945	0.953	0.008	1.008	0.008	0.949	127.368
0.078	0.069	0.922	0.932	0.010	1.011	0.011	0.927	101.044
0.116	0.104	0.884	0.896	0.012	1.014	0.014	0.890	83.100
0.144	0.130	0.856	0.870	0.014	1.016	0.016	0.863	73.575
0.154	0.140	0.846	0.860	0.014	1.017	0.016	0.853	72.018

Now, from this once we get that data we can just do the know table to find out the, this parameters to calculate the integral, graphical integration. So, y y i 1 minus y and 1 minus y i and also y minus y i from this data, we can calculate all these parameters ok.

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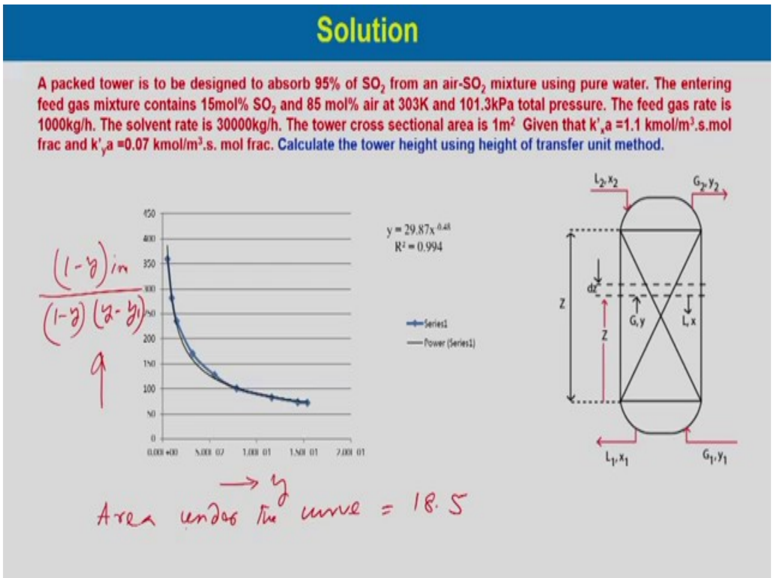

So, after this we plot them in the figure and if we plot in the y axis is 1 minus y i m divided by 1 minus y into y minus y i and this is y. So, we can obtain the area under the curve, which is know 18.5. So, from this we can get the N t G, which is area under the curve of that integral equation.

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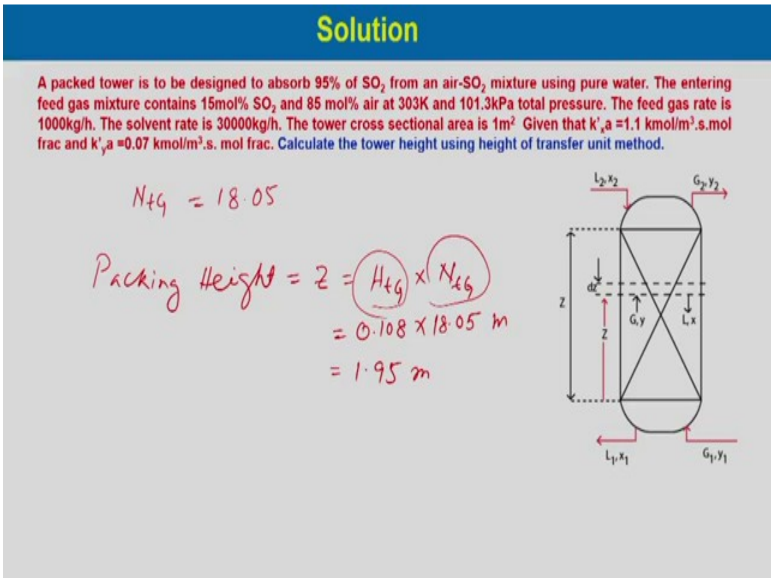

So, now we can know calculate N t G which is equal to 18.05. So, packing height would be Z is equal to H t G into N t G and if you substitute the values of H t G 0.108 into 18.05.

So, this much metre; so, it will give 1.95 metre. So, this way we can design the packing height required for a particular separation, based on height of transfer unit and the number of transfer unit.

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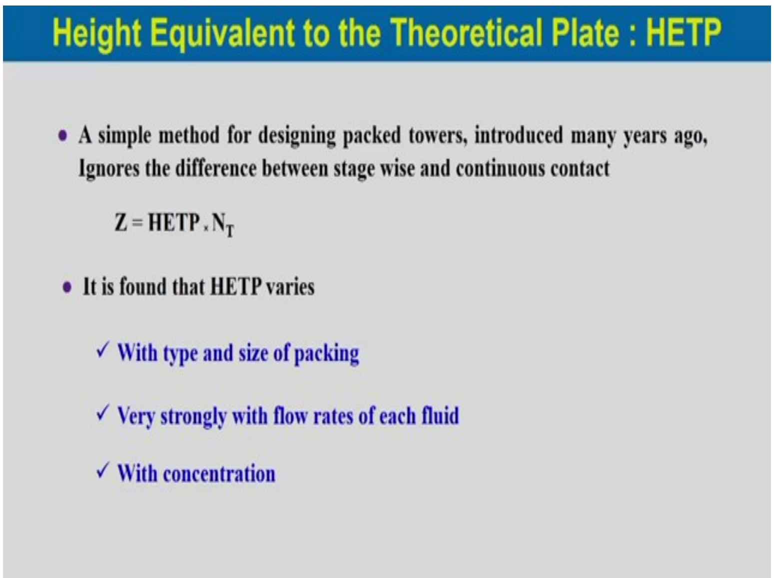

There is one method which called know height equivalent to the theoretical plate it is HETP method. A brief introduction to this is that it is very simple method for designing packed towers and this is introduced many years ago and it does not take into account the stage wise and continuous contact because of this know ignoring this two differences between the stage wise and the continuous contact. So, the design data is not know used know in the practical application.

So, here in this case is Z height of the packing is equal to H E T P into N T. H E T P is the height equivalent to a theoretical plate. So, for a theoretical plate the amount of height required for that change is considered over here and then multiplied by the transfer unit to calculate the Z. And later it is found that the H E T P height equivalent to a theoretical plate varies with different parameters like with type and size of packing. So, and then it is very strongly with know flow rate of each fluid, also it changes H E T P varies with the concentration.

So, because of this no variation, it is very difficult to design based on H E T P method.

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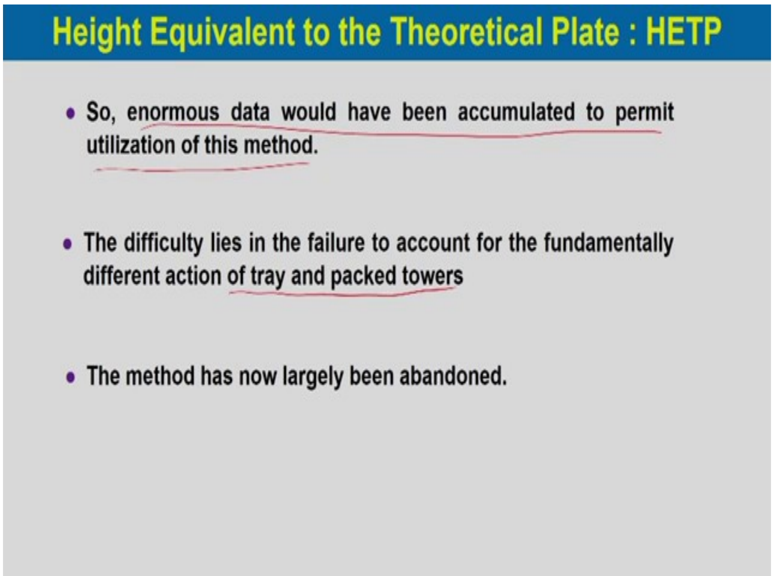

So, to calculate the height of the packing using the H E T P method, it requires enormous data which need to use to calculate the height of the packing, required for a particular separation, the difficulty lies in the failure of account of the fundamentally different actions of tray and packed column, because that tray column occurs as stage wise contact and packed towers occurs in continuous contact, because of this differences, the difficulties lies for the design over here. So, the method has now been abandoned, is not used. So, with this I conclude for this lecture and thank you for attending this lecture and we will continue our design of packed towers in next lecture.