Mass Transfer Operations-I

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Lecture - 22
Design of packed column absorber based on the Individual Mass Transfer Coefficient

Welcome to the 2nd lecture of module 4 of Mass Transfer Operation. In this module we are discussing absorption and in the last class or in the last lecture we have discussed mainly introduction on absorption process.

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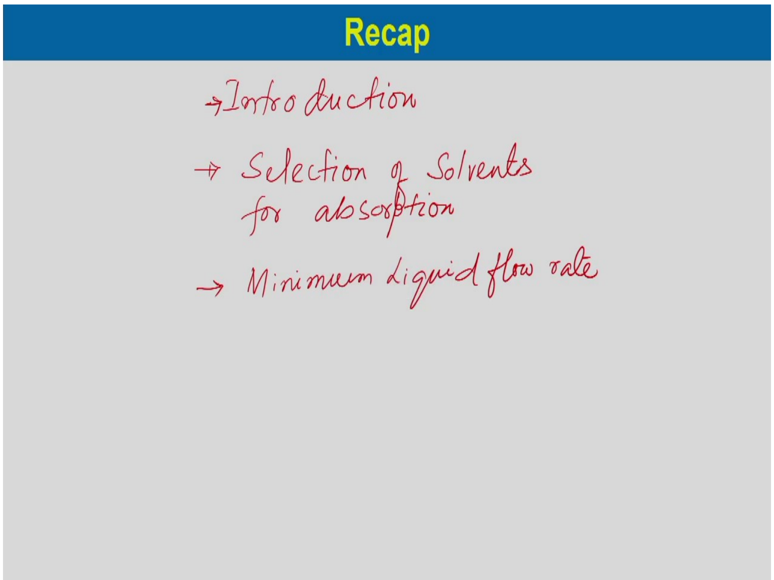

Recap

→ Introduction

→ Selection of Solvents for absorption

→ Minimum liquid flow rate

We have also discussed the selection of different solvents for absorption and third thing we have considered how to determine the minimum liquid flow rate for absorption. So, minimum liquid flow rate.

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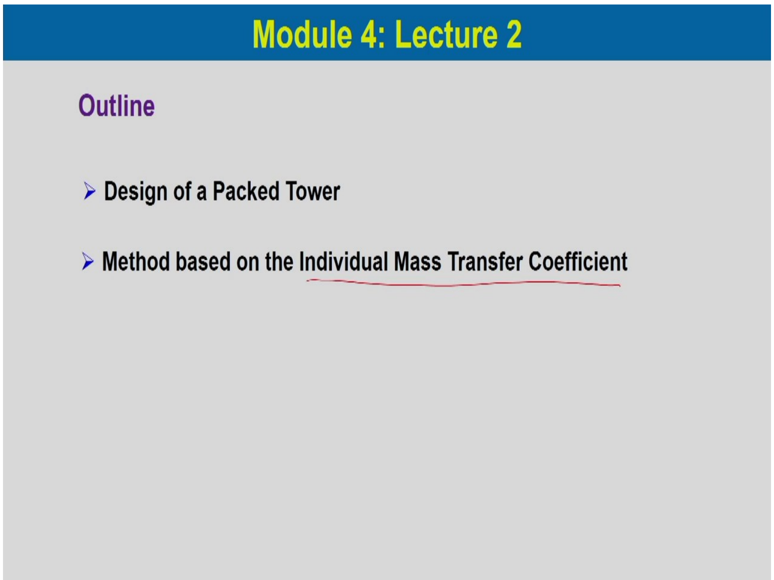

Module 4: Lecture 2

Outline

- Design of a Packed Tower
- Method based on the Individual Mass Transfer Coefficient

So, in this lecture we will consider primarily on the design of packed towers and in this we will consider first method based on the individual mass transfer coefficient. So, mostly will concentrate in this lecture individual mass transfer coefficient method.

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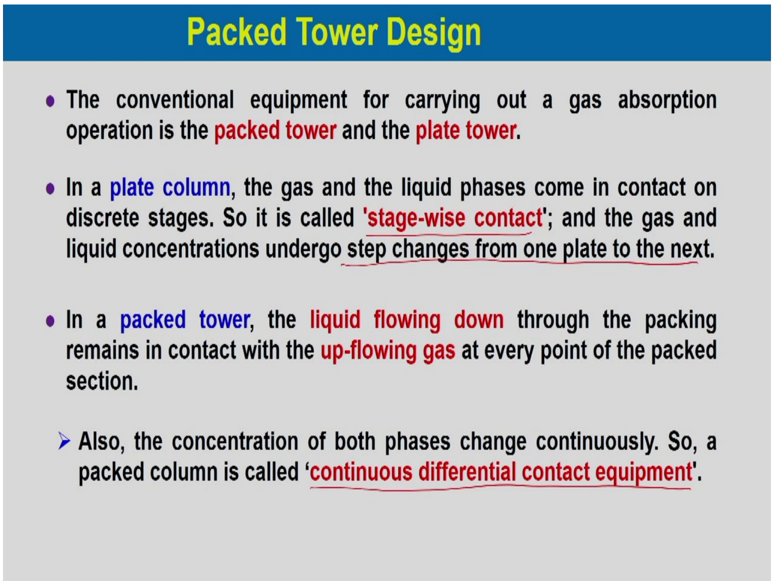

Packed Tower Design

- The conventional equipment for carrying out a gas absorption operation is the packed tower and the plate tower.
- In a plate column, the gas and the liquid phases come in contact on discrete stages. So it is called 'stage-wise contact'; and the gas and liquid concentrations undergo step changes from one plate to the next.
- In a packed tower, the liquid flowing down through the packing remains in contact with the up-flowing gas at every point of the packed section.
  - Also, the concentration of both phases change continuously. So, a packed column is called 'continuous differential contact equipment'.

The conventional requirement for carrying out gas absorption operation is the packed towers and the plate towers that we have already discussed. And we have seen that in plate column the gas and the liquid phases come in contact with discrete stages; so, it is called stage wise contact; that means, if the gas flows co current or counter currently in the column the liquid flows from the top through different trays and no exit at the bottom, and then gas enters at the bottom and it exit at the top.

So, if so happen then the gas generally in a plate columns is goes through the perforation of the plate and it passes through the liquid pool. So, the mass transfer happens when the gas and liquid come in contact in the stages with respect to the liquid pool available on each stage.

So, the transfer happens only when there is a liquid pool, and in the empty space between the trays where there is no liquid present there will not be any mass transfer. So, again the mass transfer will happen to the next stage when there will be gas and liquid contact. So, that is why in a plate column the contact of the gas and liquid is discrete and hence it is called stage wise contact and the gas and liquid concentration undergo step change from one plate to the next plate. Whereas in case of packed column the liquid flowing down through the packing remains in contact with the up flowing gas at every point of the packed section.

So, as you know in packed section the packing are no random or in the in a structured way it is packed inside a column. So, when the liquid flows, it flows onto the surface of the packing material and it is continuous from top to bottom and the gas also passes through the available space between the packing materials. So, at every stage of the column there is intimate contact between gas and liquid. So, that is why this type of packed column is called as continuous differential contact equipment. So, there is no step change so, every no point there is a change of concentration as the gas flows from bottom to top or liquid flows from top to bottom.

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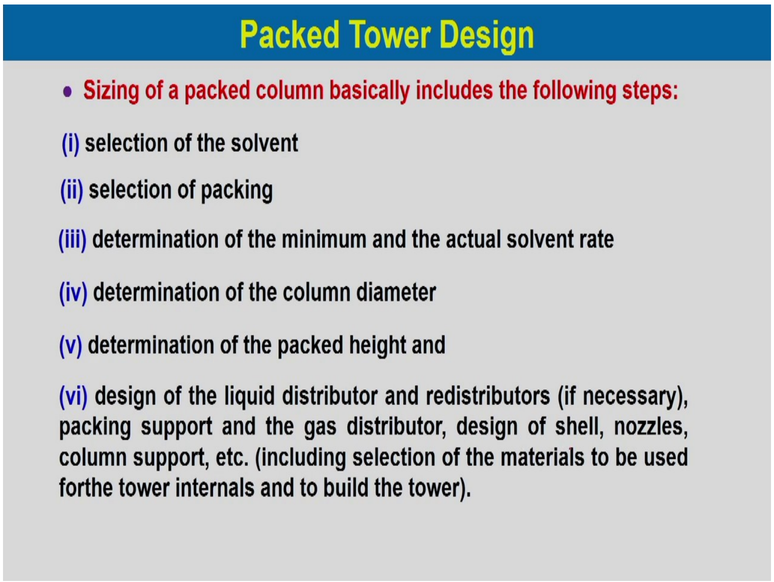

Packed Tower Design

- Sizing of a packed column basically includes the following steps:

(i) selection of the solvent

(ii) selection of packing

(iii) determination of the minimum and the actual solvent rate

(iv) determination of the column diameter

(v) determination of the packed height and

(vi) design of the liquid distributor and redistributors (if necessary), packing support and the gas distributor, design of shell, nozzles, column support, etc. (including selection of the materials to be used forthe tower internals and to build the tower).

Now, the sizing of a packed column basically includes the few stage which we need to consider, first is the selection of the solvent and second is selection of packing then determination of the minimum and actual solvent rate; determination of the column diameter, determination of packed height. And the design of the liquid distributor and redistributor if necessary packing support and the gas distributor, design of shells, nozzles, column support including selection of the materials to be used for the tower internals and to build the tower.

So, among these the sizing of the packed towers, the selection of the solvent already we have discussed in our last lecture, then selection of packing material different type of packing material we have already discussed, but in detail no design of the packing material you will learn in your design course., But it is mostly to enhance the interfacial area, reduce the pressure drop inside the columns. So, based on that, we need to select the packing material.

Then determination of the minimum liquid rate or the solvent rate and then actual solvent rate so, that we have already discussed in the last class. Determination of the column diameter also we have discussed to some extent during the discussion of our equipment. Now in this no lecture we will primary concentrate on the determination of the packing height.

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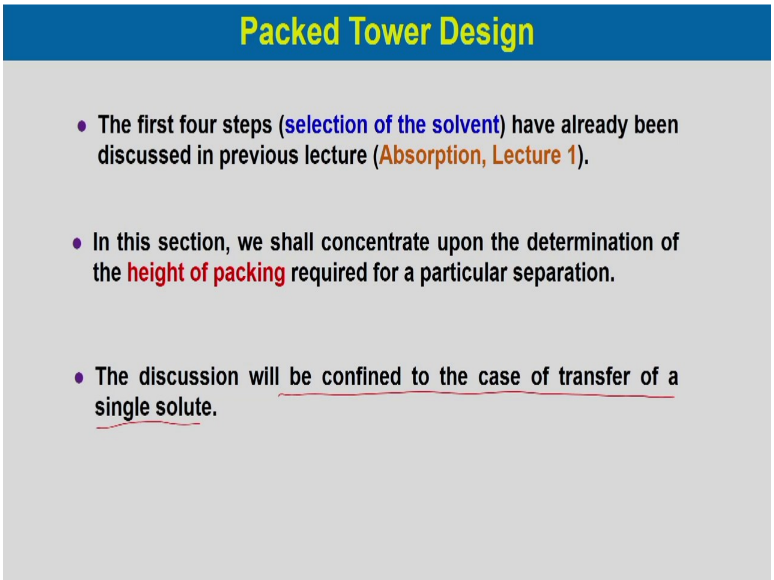

Packed Tower Design

- The first four steps (selection of the solvent) have already been discussed in previous lecture (Absorption, Lecture 1).
- In this section, we shall concentrate upon the determination of the height of packing required for a particular separation.
- The discussion will be confined to the case of transfer of a single solute.

The first 4 steps that is selection of the solvents have already been discussed in previous lecture in absorption lecture 1. In this sections we shall concentrate upon the determination of the height of packing required for a particular separation. The discussion will be confined to the case transfer of a single solute mostly we will considered the single solute transfer and how height of the packed tower is required that we need to calculate.

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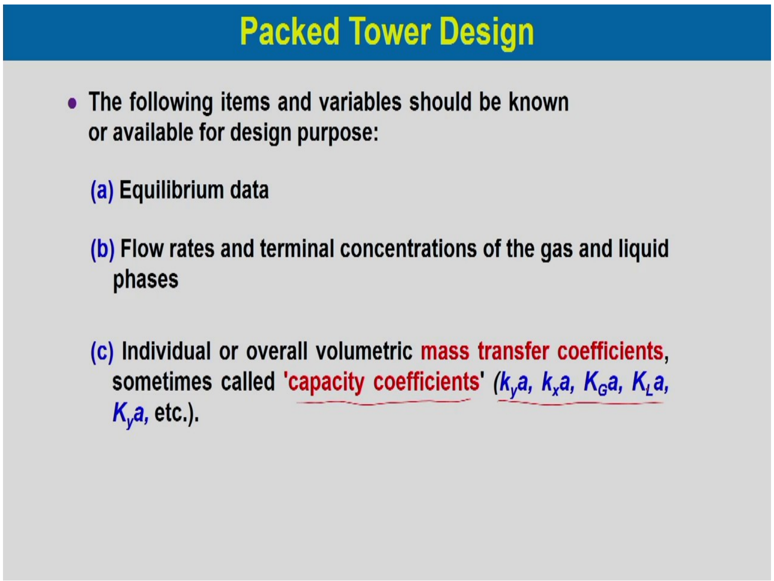

Packed Tower Design

- The following items and variables should be known or available for design purpose:

  (a) Equilibrium data

  (b) Flow rates and terminal concentrations of the gas and liquid phases

  (c) Individual or overall volumetric mass transfer coefficients, sometimes called 'capacity coefficients' (k_ya, k_xa, K_Ga, K_La, K_ya, etc.).

The following items and variables should be known or available for design purpose, what are those parameters or variables? That is equilibrium data should be available with us the flow rate and the terminal concentrations of the gas and liquid phases that should be available. Individual or overall volumetric mass transfer coefficient sometimes called ‘capacity coefficients’ and which is based on the gas phase and liquid phase we should have those data available with us that is k y a, small k y a small k x a and capital K G a and capital K L a capital K y a etcetera. These are the no parameters for that particular systems we need to or the mass transfer coefficient either individual or overall mass transfer coefficient should be available for finding out the packed tower design, that is the height of the tower.

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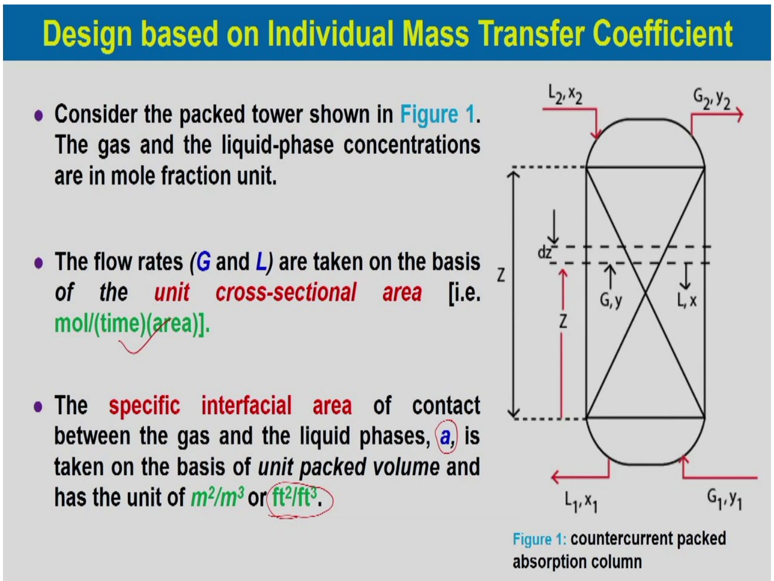

Design based on Individual Mass Transfer Coefficient

- Consider the packed tower shown in Figure 1. The gas and the liquid-phase concentrations are in mole fraction unit.
- The flow rates (*G* and *L*) are taken on the basis of *the unit cross-sectional area* [i.e. mol/(time)(area)].
- The specific interfacial area of contact between the gas and the liquid phases, *a*, is taken on the basis of *unit packed volume* and has the unit of m^2/m^3 or ft^2/ft^3.

Figure 1: countercurrent packed absorption column

We will concentrate first a design based on individual mass transfer coefficient, considered the packed tower which is shown over here the gas and liquid phase contact are in mole fractions unit that is small x and small y. So, the flow rate G and L are taken on the basis of the unit cross sectional area that is mole per unit time per unit area. So, per unit cross sectional area L 1 L 2, G 1 G 2 and G and L these are the gas and liquid flows. The specific interfacial area of contact between the gas and the liquid which is small a is taken on the basis of the unit packed volume and has a unit of either metre square per metre cube or feet square per feet cube. So, per a no unit volume of the packing.

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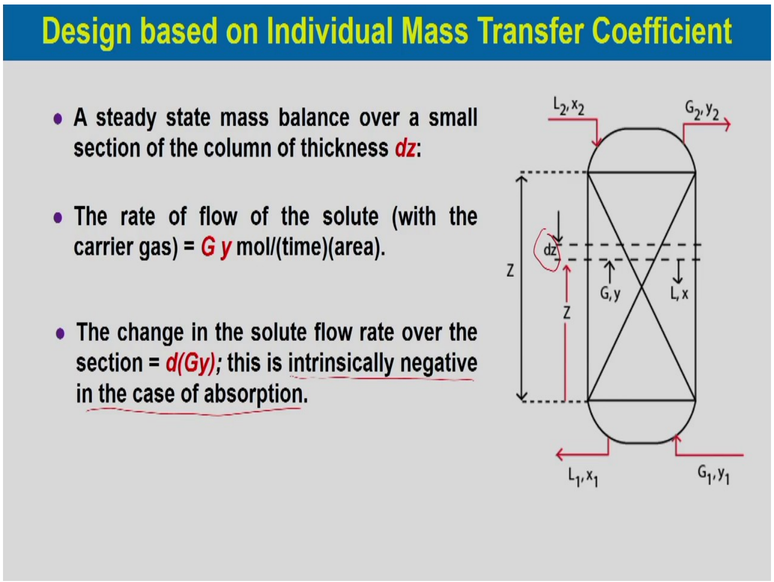

Design based on Individual Mass Transfer Coefficient

- A steady state mass balance over a small section of the column of thickness *dz*:
- The rate of flow of the solute (with the carrier gas) = $G\,y$ mol/(time)(area).
- The change in the solute flow rate over the section = $d(Gy)$; this is intrinsically negative in the case of absorption.

Now, if we consider a steady state mass balance over a small section of the column of thickness d z which is shown over here small thickness d z. So, the steady state mass balance would be the rate of flow of the solute with the career gas would be G into y mole per time into area, G into y.

So, which is the gas flow rate or the solute gas flow rate, the change in the solute flow rate in this section would be d G y, this is intrinsically negative in case of absorption because the solute transfer from the gas phase to the liquid phase. So, since the solute concentration is decreasing as the gas flows from one location to the other location. So, it is intrinsically negative.

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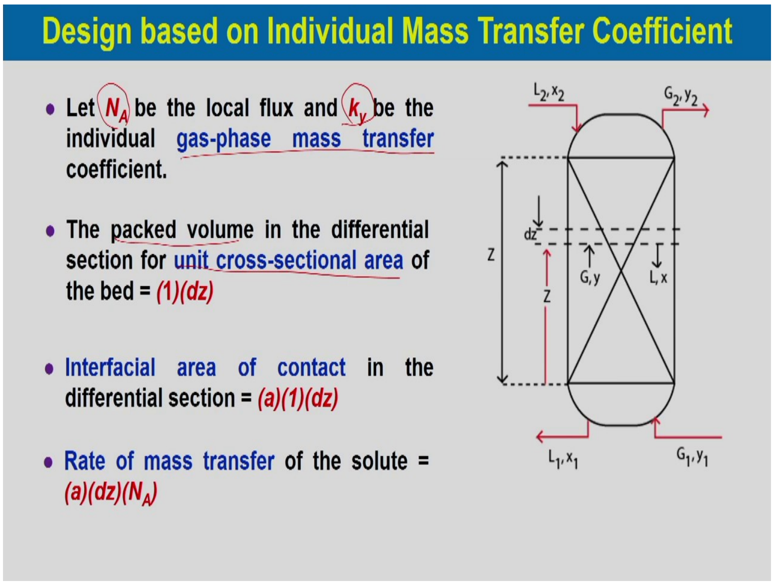

Design based on Individual Mass Transfer Coefficient

- Let N_A be the local flux and k_y be the individual gas-phase mass transfer coefficient.
- The packed volume in the differential section for unit cross-sectional area of the bed = $(1)(dz)$
- Interfacial area of contact in the differential section = $(a)(1)(dz)$
- Rate of mass transfer of the solute = $(a)(dz)(N_A)$

Now let N A be the local flux and small k y be the individual gas phase mass transfer coefficient. So, small k y and N A is the local flux, then the packed volume in the differential section for unit cross sectional area if we consider. So, the packed volume of the bed we can get one into dz; so, that is the packed volume. Now the interfacial area of contact in the differential section is a into 1 into d z. So, this is the interfacial area of contact, now the rate of mass transfer of the solute would be a d z into N A. So, that is the rate of no solute transfer or mass transfer of the solute.

Now, we know the packed volume, we know the interfacial area of contact and also the rate of mass transfer.

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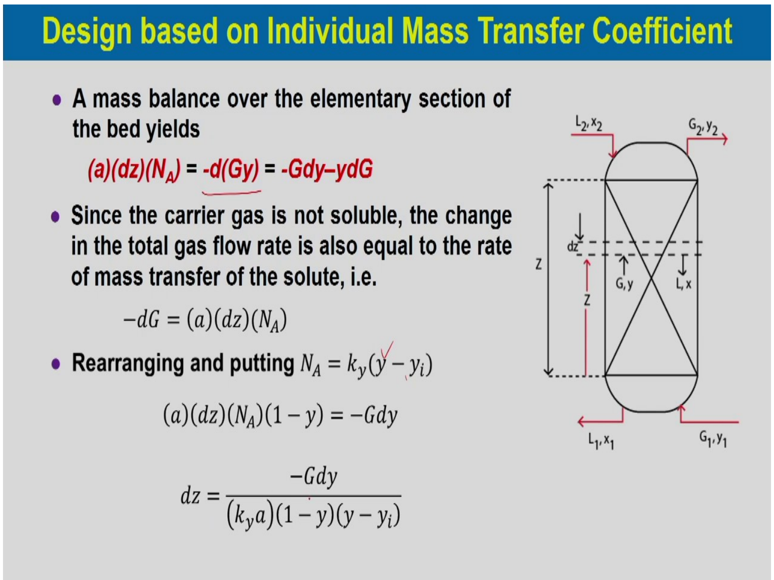

Design based on Individual Mass Transfer Coefficient

- A mass balance over the elementary section of the bed yields

  $(a)(dz)(N_A) = -\underline{d(Gy)} = -Gdy - ydG$

- Since the carrier gas is not soluble, the change in the total gas flow rate is also equal to the rate of mass transfer of the solute, i.e.

  $$-dG = (a)(dz)(N_A)$$

- Rearranging and putting $N_A = k_y(y - y_i)$

  $$(a)(dz)(N_A)(1-y) = -Gdy$$

  $$dz = \frac{-Gdy}{(k_y a)(1-y)(y-y_i)}$$

So, a mass balance over the elementary section of the bed which will yield a into d z into N A would be equal to minus d G y which is equal to minus G d y minus y d g. So, since the carrier gas is not soluble the change in the total gas flow rate is also equal to the rate of mass transfer of the solute.

So, we can write minus d G would be equal to a d z into N A, if we rearrange and putting N A is equal to k y into y minus y I, y is the concentration in the bulk and y i is the interfacial concentration in between the gas and liquids. So, flux N A would be k y y minus y i. So, we can write a d z into N A 1 minus y would be equal to minus G d y, if you rearrange d z would be minus G d y divided by k y a into 1 minus y into y minus y i.

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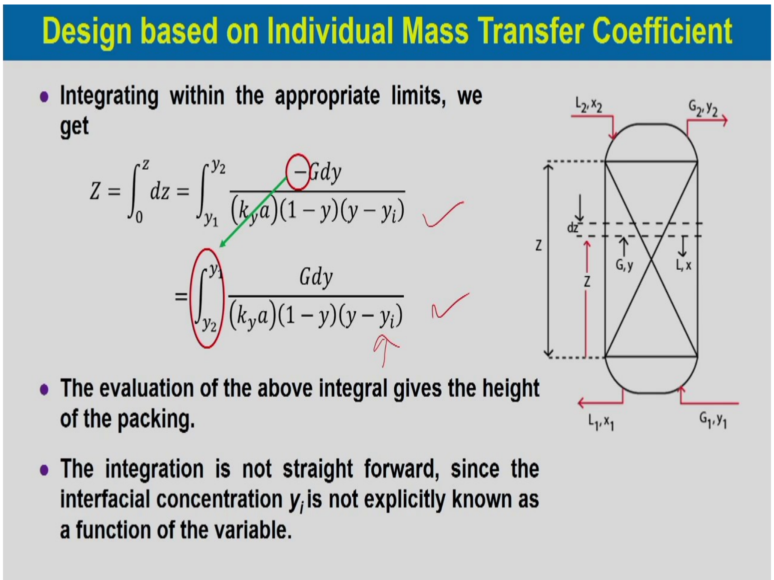

Design based on Individual Mass Transfer Coefficient

- Integrating within the appropriate limits, we get

$$Z = \int_0^z dz = \int_{y_1}^{y_2} \frac{-G dy}{(k_y a)(1-y)(y-y_i)}$$

$$= \int_{y_2}^{y_1} \frac{G dy}{(k_y a)(1-y)(y-y_i)}$$

- The evaluation of the above integral gives the height of the packing.
- The integration is not straight forward, since the interfacial concentration y_i is not explicitly known as a function of the variable.

Now, if we just integrate within the appropriate limit, we get z would be equal to integral 0 to z d z would be equal to integral y 1 to y 2 minus G d y divided by k y a into 1 minus y into y minus y i, now you just change the limit from y 2 to y 1. So, this negative sign will be observed. So, we will have integral y 2 to y 1 z d y divided by k y a 1 minus y into y minus y i. The evaluation of the integral which is given over here for the height of the packing requires the calculation of y i.

So, that is the interfacial concentration. So, the integration is not straight forward since the interfacial concentration y i is not explicitly known as the function of the variables since y i is not known the these integration is not. So, straight forward. So, we have to find out a ways to find out the interfacial concentration.

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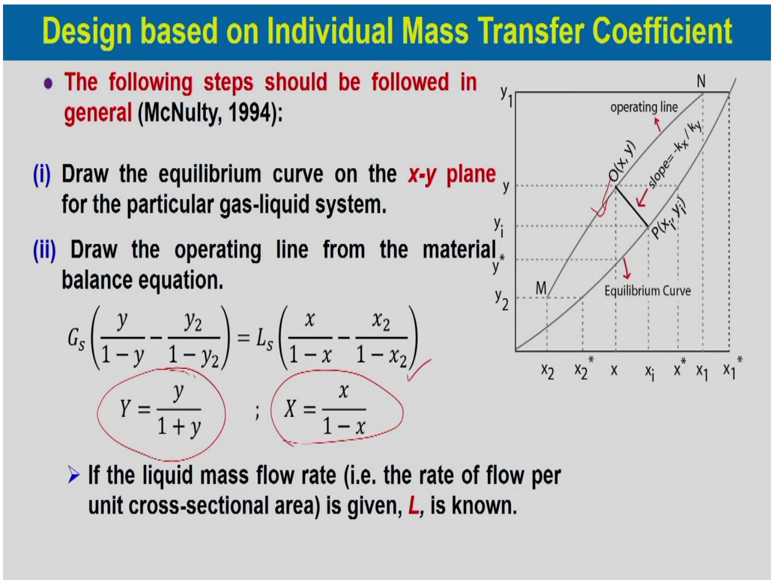

Design based on Individual Mass Transfer Coefficient

- The following steps should be followed in general (McNulty, 1994):

(i) Draw the equilibrium curve on the *x-y* plane for the particular gas-liquid system.

(ii) Draw the operating line from the material balance equation.

$$G_s\left(\frac{y}{1-y}-\frac{y_2}{1-y_2}\right)=L_s\left(\frac{x}{1-x}-\frac{x_2}{1-x_2}\right)$$

$$Y=\frac{y}{1+y}\quad ; \quad X=\frac{x}{1-x}$$

➤ If the liquid mass flow rate (i.e. the rate of flow per unit cross-sectional area) is given, *L*, is known.

Now, the following general steps should be followed to calculate that, first we need to draw the equilibrium curve on the x y plane for the particular gas liquid systems and then the draw the operating line from the material balance equation. So, we have material balance equation. So, we can get the operating line equation here.

So, G s into y by 1 minus y minus y 2 by 1 minus y would be equal to L s into x by 1 minus x minus x 2 by 1 minus x 2 and here small y capital Y as we have already know discuss, this is the relation. If the liquid mass flow rate that is the rate of flow per unit cross sectional area is given as L and which is known.

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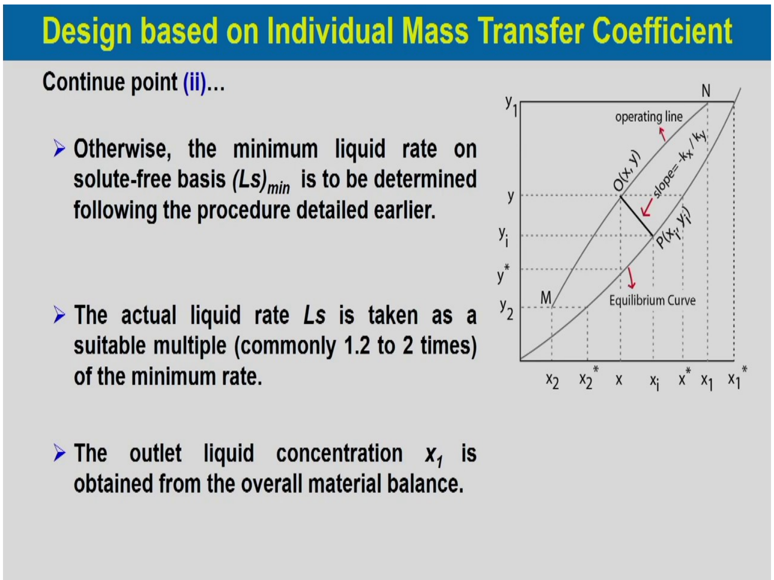

Design based on Individual Mass Transfer Coefficient

Continue point (ii)...

- Otherwise, the minimum liquid rate on solute-free basis $(Ls)_{min}$ is to be determined following the procedure detailed earlier.
- The actual liquid rate *Ls* is taken as a suitable multiple (commonly 1.2 to 2 times) of the minimum rate.
- The outlet liquid concentration x_1 is obtained from the overall material balance.

In that case the minimum liquid rate on the solute free basis L min is to be determine following the procedure detailed earlier; that means, no if L is known that is fine, if it is not known then we have to find out the pinch point and through the slope of the operating line and we have to calculate the minimum liquid flow rates. And then we have to use the actual liquid flow rate should be taken as the suitable multiples which will vary between 1.5 to 2 times of the minimum rate.

So if you do not have data for the liquid flow rate we have to know the slope of the operating line and we have to calculate from the pinch point the minimum liquid rate and then we can calculate the actual liquid rate. The outlet liquid concentration x 1 is obtained from the overall material balance.

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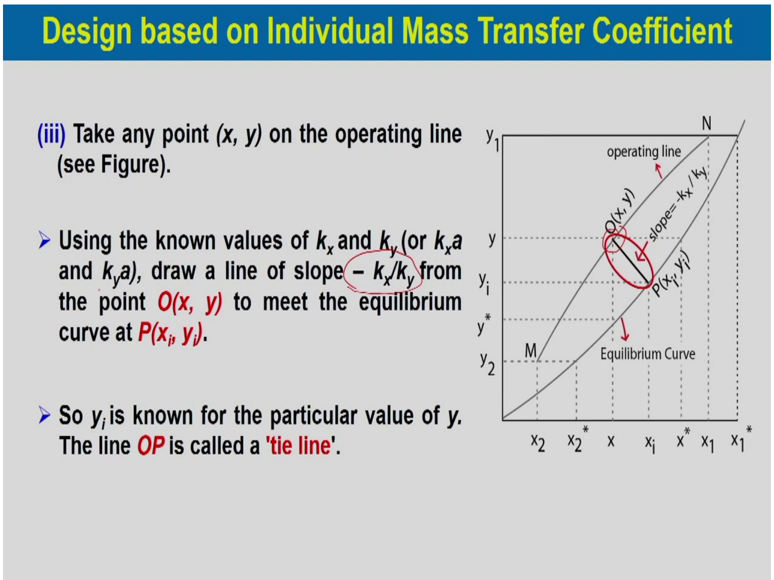

Design based on Individual Mass Transfer Coefficient

(iii) Take any point *(x, y)* on the operating line (see Figure).

- Using the known values of k_x and k_y (or k_xa and k_ya), draw a line of slope $-k_x/k_y$ from the point *O(x, y)* to meet the equilibrium curve at *P(x_i, y_i)*.
- So y_i is known for the particular value of *y*. The line *OP* is called a 'tie line'.

So, this is the procedure we have to follow then take any point x y on the operating line. So, at any point if we take see figure over here we can take any point x y over here using the known values of k x and k y or k x a and k y a we can calculate the slope of the operating line from the point O x to meet the equilibrium curve at point x i y i. y i is known for the particular values of y, the line op over here you can see line op is called the tie line. So, which will no give the interfacial concentration xi and y i.

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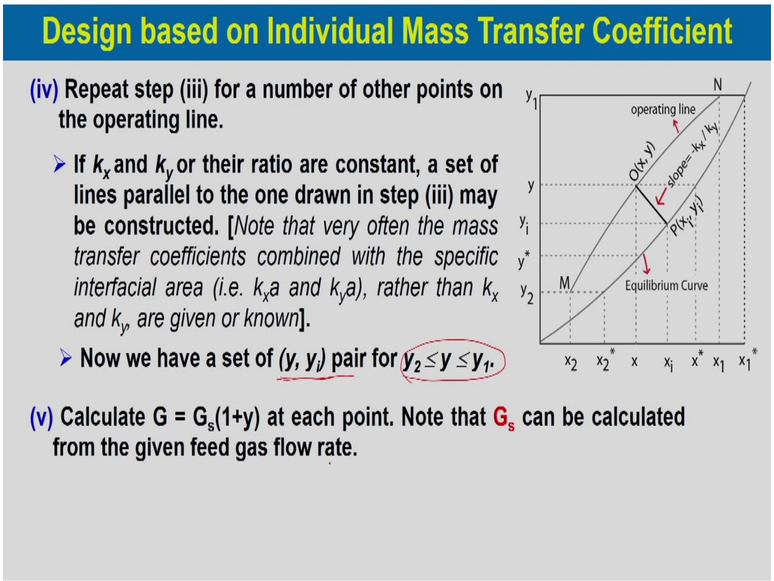

Design based on Individual Mass Transfer Coefficient

(iv) Repeat step (iii) for a number of other points on the operating line.

- If k_x and k_y or their ratio are constant, a set of lines parallel to the one drawn in step (iii) may be constructed. [*Note that very often the mass transfer coefficients combined with the specific interfacial area (i.e. k_xa and k_ya), rather than k_x and k_y, are given or known*].
- Now we have a set of *(y, y_i)* pair for $y_2 \le y \le y_1$.

(v) Calculate G = $G_s(1+y)$ at each point. Note that G_s can be calculated from the given feed gas flow rate.

Now we have to repeat the steps for a number of other points on the operating line if k x and k y or their ratio are constant a set of lines parallel to the one drown in step 3 may be constructed. So, if this is the straight line, then we can parallel line we can draw in a no multiple points and we can get the multiple data for a set of no x and y we can get a set of x i and y i..

Please note that very often the mass transfer coefficient combined with the specific interfacial are88a that is k x a and k y a rather than k x and k y are given or no because sometimes the total interfacial area may not be available. So, it is no given in terms of k x a and k y a now we have set of y y i here for y 2 less than equal to y and which is less than equal to y 1. So, with this limit we have a set of y and y i pair. So, from the no tie line we can obtain for a particular system.

Now, we can calculate G is equal to G s 1 plus y at each point, note that G s can be calculated from the given feed gas flow rate.

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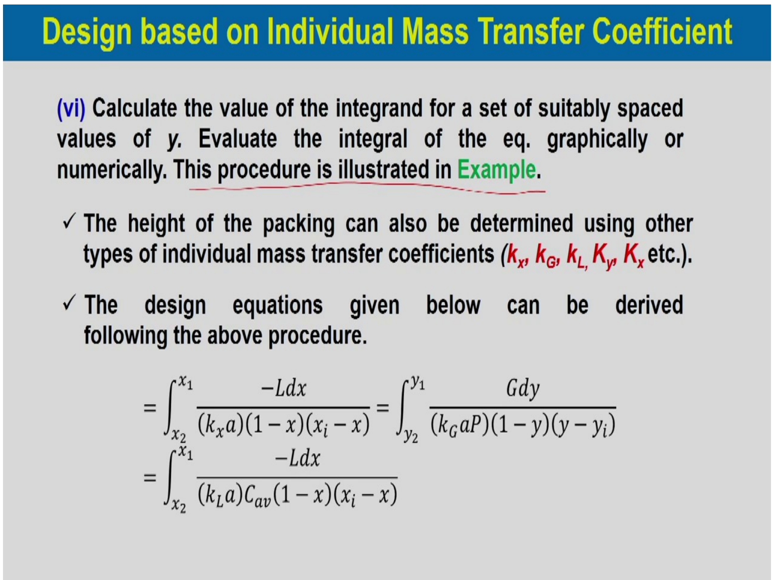

Design based on Individual Mass Transfer Coefficient

(vi) Calculate the value of the integrand for a set of suitably spaced values of *y*. Evaluate the integral of the eq. graphically or numerically. This procedure is illustrated in Example.

- ✓ The height of the packing can also be determined using other types of individual mass transfer coefficients (k_x, k_G, k_L, K_y, K_x etc.).
- ✓ The design equations given below can be derived following the above procedure.

$$= \int_{x_2}^{x_1} \frac{-Ldx}{(k_x a)(1-x)(x_i - x)} = \int_{y_2}^{y_1} \frac{Gdy}{(k_G aP)(1-y)(y-y_i)}$$

$$= \int_{x_2}^{x_1} \frac{-Ldx}{(k_L a)C_{av}(1-x)(x_i - x)}$$

Now, calculate the values of the integrant for a set of suitably spaced values of y, then evaluate the integral for the equation graphically or numerically and this procedure will be illustrated later in an example. So, we will see how to calculate that, the height of the packing then can be determined using the other type of individual mass transfer coefficient, it maybe k x k G k L capital K y capital K x and so on. The design equation given below can be derived following the above procedure.

So, this is the design equation integral x 2 to x 1 minus L into dx divided by k x a into 1 minus x into x i minus x which would be equal to integral y 2 to y 1 G d y divided by k G a p t total pressure into 1 minus y into y minus y i. Or it can be in terms of the liquid average concentration we can write integral x 2 to x 1 minus L d x divided by k L a c a b that is average concentration into one minus x into x i minus x. So, this way we can calculate the height of the tower.

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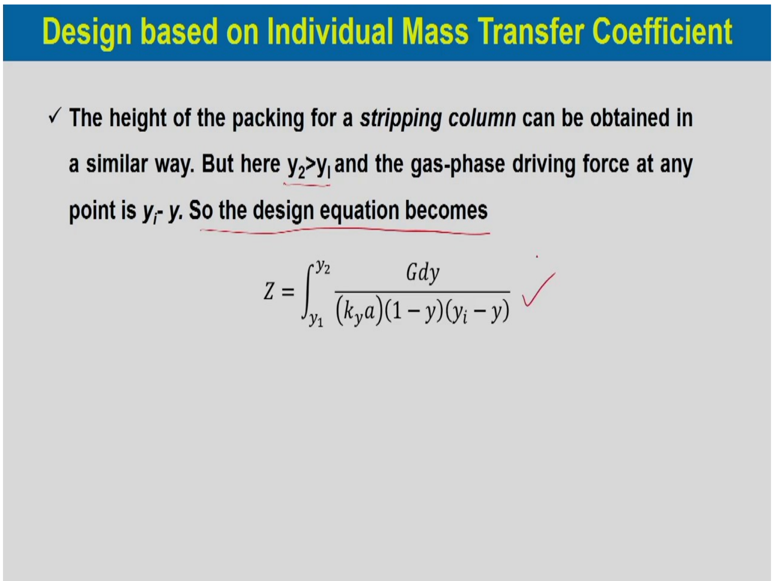

Design based on Individual Mass Transfer Coefficient

✓ The height of the packing for a *stripping column* can be obtained in a similar way. But here $y_2 > y_1$ and the gas-phase driving force at any point is $y_i - y$. So the design equation becomes

$$Z = \int_{y_1}^{y_2} \frac{G\,dy}{(k_y a)(1-y)(y_i - y)}$$

The height of packing for a stripping column can be obtained in a similar way, but here y 2 should be greater than y 1 and the gas phase driving force at any point is y i minus y. So, the design equation will change to z is equal to integral y 1 to y 2 G d y divided by k y a 1 minus y into y i minus y. So, almost similar procedure will be followed in case design of the packing for the stripping column.

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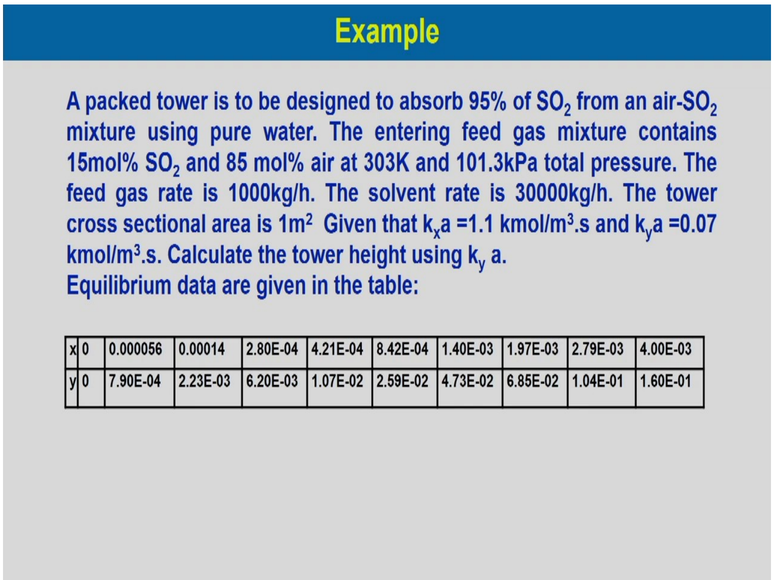

Example

A packed tower is to be designed to absorb 95% of SO_2 from an air-SO_2 mixture using pure water. The entering feed gas mixture contains 15mol% SO_2 and 85 mol% air at 303K and 101.3kPa total pressure. The feed gas rate is 1000kg/h. The solvent rate is 30000kg/h. The tower cross sectional area is $1 m^2$ Given that $k_x a$ =1.1 $kmol/m^3.s$ and $k_y a$ =0.07 $kmol/m^3.s$. Calculate the tower height using k_y a.
Equilibrium data are given in the table:

x	0	0.000056	0.00014	2.80E-04	4.21E-04	8.42E-04	1.40E-03	1.97E-03	2.79E-03	4.00E-03
y	0	7.90E-04	2.23E-03	6.20E-03	1.07E-02	2.59E-02	4.73E-02	6.85E-02	1.04E-01	1.60E-01

Now, let us take an example how to calculate the tower height using k y a, 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 feet gas mixture contains 15 mole percent sulphur dioxide and 85 mole percent air at 303 Kelvin and 101.3 kilo Pascal total pressure. The feed gas rate is given which is 1000 kg per hour the solvent rate is also given which is 30000 kg per hour the tour cross sectional area is 1 meter square and the data which are given k x a which is 1.1 kilo mole per metre cube second and k y a is 0.07 kilo mole per metre cube second. Now we have to calculate height of the tower using k y a, the data which are provided at the equilibrium data which is x and y.

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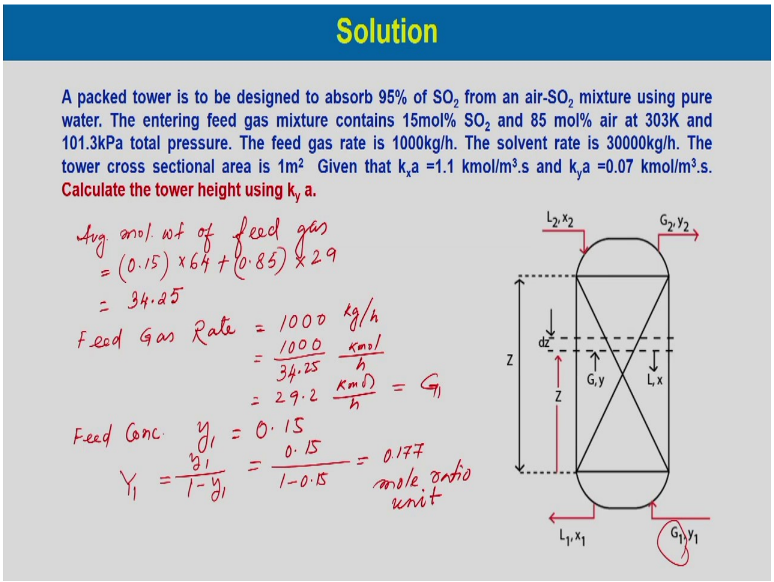

Solution

A packed tower is to be designed to absorb 95% of SO_2 from an air-SO_2 mixture using pure water. The entering feed gas mixture contains 15mol% SO_2 and 85 mol% air at 303K and 101.3kPa total pressure. The feed gas rate is 1000kg/h. The solvent rate is 30000kg/h. The tower cross sectional area is 1m² Given that $k_x a$ =1.1 kmol/m³.s and $k_y a$ =0.07 kmol/m³.s.

Calculate the tower height using k_y a.

Avg. mol. wt of feed gas

$$= (0.15) \times 64 + (0.85) \times 29$$

$$= 34.25$$

Feed Gas Rate $= 1000$ kg/h

$$= \frac{1000}{34.25} \frac{\text{kmol}}{\text{h}}$$

$$= 29.2 \frac{\text{kmol}}{\text{h}} = G_1$$

Feed Conc. $y_1 = 0.15$

$$Y_1 = \frac{y_1}{1-y_1} = \frac{0.15}{1-0.15} = 0.177$$

mole ratio unit

So, now for this sketch, now same sketch we can use over here and we need to calculate the average molecular weight of the feed gas, average molecular weight of feed gas which is equal to we have no 15 mole percent of sulphur dioxide. So, 0.15 multiplied by its molecular weight is 64 plus we have 85 percent air. So, 0.85 into the molecular weight of air is 29 and. So, it will give no 34.25.

Now, we need to calculate the feed gas rate. and this is given as thousand kg per hour. Now if we convert to no kilo mole per hour. So, this should be equal to 1000 divided by the average molecular weight is 34.25 would be kilo mole per hour and which is about 29.2 k mole per hour. So, this is basically G 1; so, which is entering feed gas; now feed concentration which is y 1 is given as no 15 percent 0.15. So, if we wanted to calculate in mole ratio unit. So, it is capital Y 1 would be equal to small y 1 divided by 1 minus y 1 which is equal to 0.15 divided by 1 minus 0.15 and this would be about 0.177, this is mole ratio unit.

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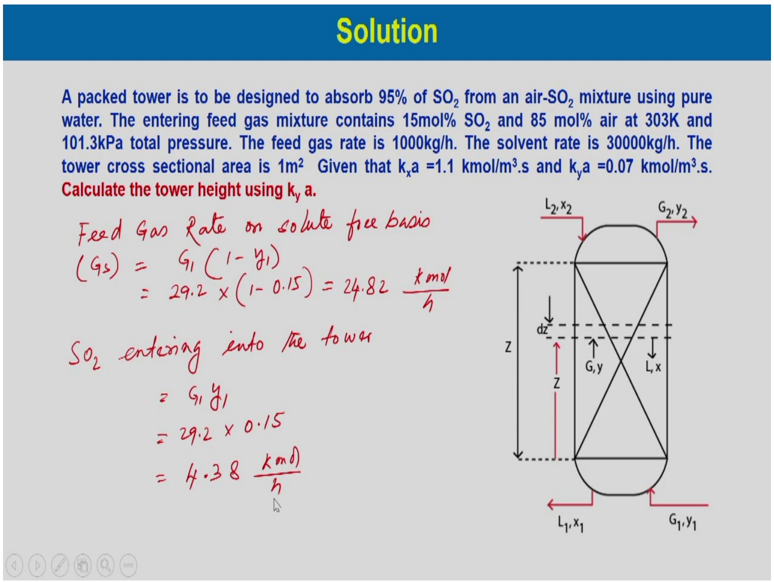

Solution

A packed tower is to be designed to absorb 95% of SO_2 from an air-SO_2 mixture using pure water. The entering feed gas mixture contains 15mol% SO_2 and 85 mol% air at 303K and 101.3kPa total pressure. The feed gas rate is 1000kg/h. The solvent rate is 30000kg/h. The tower cross sectional area is 1m² Given that k_xa =1.1 kmol/m³.s and k_ya =0.07 kmol/m³.s.

Calculate the tower height using k_y a.

Feed Gas Rate on solute free basis

$$(G_s) = G_1(1-y_1)$$
$$= 29.2 \times (1-0.15) = 24.82\ \frac{kmol}{h}$$

SO_2 entering into the tower

$$= G_1 y_1$$
$$= 29.2 \times 0.15$$
$$= 4.38\ \frac{kmol}{h}$$

Now, we need to calculate the feed gas rate on solute free basis. So, feed gas rate on solute free basis this should be basically G s which is equal to G 1 into 1 minus y 1. So, G 1 is 29.2 into 1 minus 0.15 that is 15 percent no feed gas concentration. So, it would be equal to 24.82 kilo mole per hour. Now the S o 2 which is entering into the tower is equal to G 1 y 1, now if we substitute the values G 1 is 29.2 and the y 1 is point one five 0.15 15 percent. So, it is 4.38 kilo mole per hour.

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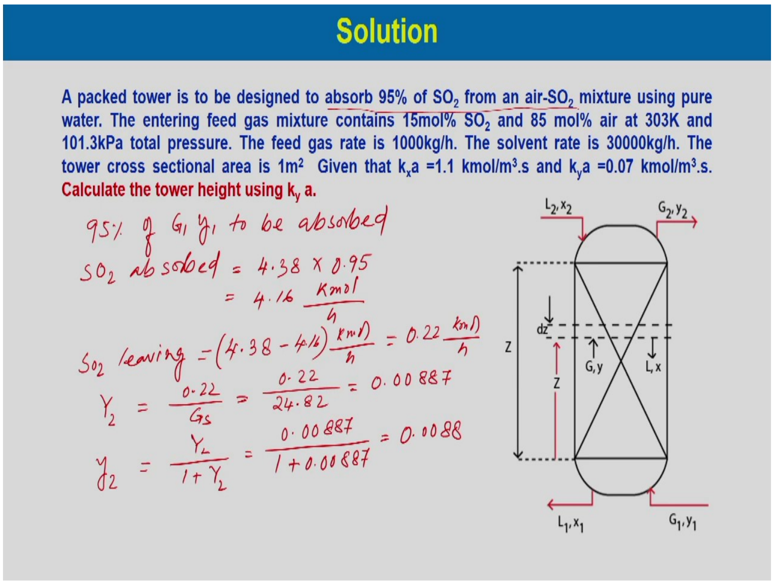

Solution

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Calculate the tower height using k_y a.

95% of $G_1 y_1$ to be absorbed

$$SO_2 \text{ absorbed} = 4.38 \times 0.95$$
$$= 4.16\ \frac{Kmol}{h}$$

$$SO_2 \text{ leaving} = (4.38 - 4.16)\frac{kmol}{h} = 0.22\ \frac{kmol}{h}$$

$$Y_2 = \frac{0.22}{G_s} = \frac{0.22}{24.82} = 0.00887$$

$$y_2 = \frac{Y_2}{1+Y_2} = \frac{0.00887}{1+0.00887} = 0.0088$$

Now, as per the problem given is in the packed tower we have to absorb 95 percent of the SO 2 from air sulphur dioxide mixture; so, 90 percent of G 1 y 1, 95 percent of G 1 y 1 to be absorbed. So, SO 2 absorbed would be equal to 4.38 into 0.95. So, this is about 4.16 k mole per hour. So, the SO 2 which would be leaving the total SO 2 which is entering and then which is absorbed the difference between these two would be the leaving one. So, this is equal to 4.38 minus 4.16 kilo mole per hour which is equal to 0.22 kilo mole per hour.

So, now we can calculate capital y 2 would be equal to 0.22 divided by G s, which is equal to 0.22 divided by 24.82. So, this would be about 0.00887. So, we can calculate in no in mole fraction unit small y 2 would be equal to capital y 2 divided by 1 plus capital Y 2. So, which is equal to 0.00887 divided by 1 plus 0.00887, which would be equal to 0.0088. So, this is mole fraction of the exit steam or SO 2 leaving column.

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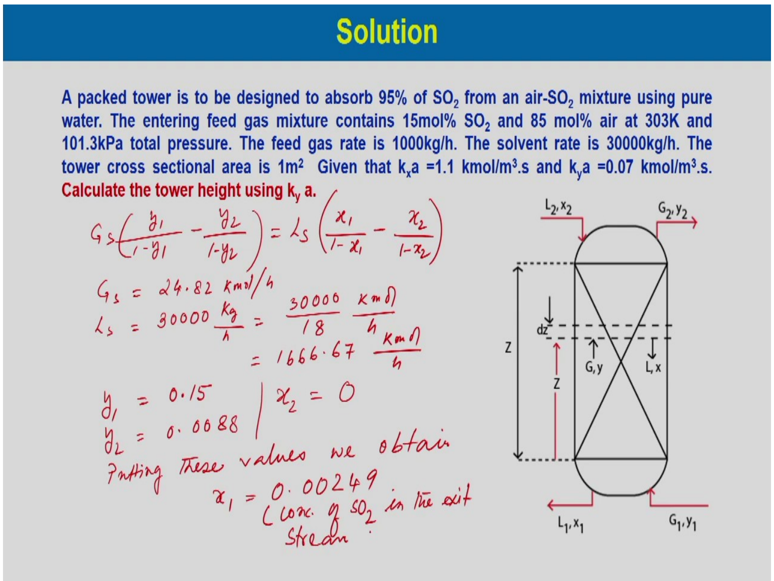

Solution

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$$G_s\left(\frac{y_1}{1-y_1}-\frac{y_2}{1-y_2}\right)=L_s\left(\frac{x_1}{1-x_1}-\frac{x_2}{1-x_2}\right)$$

$$G_s = 24.82 \text{ kmol/h}$$

$$L_s = 30000\frac{\text{kg}}{\text{h}} = \frac{30000}{18}\frac{\text{kmol}}{\text{h}} = 1666.67\frac{\text{kmol}}{\text{h}}$$

$$y_1 = 0.15 \quad\Big|\quad x_2 = 0$$

$$y_2 = 0.0088$$

Putting these values we obtain

$$x_1 = 0.00249$$

(conc. of SO_2 in the exit stream.

Now, we need to calculate the exit stream concentration x 1 the liquid phase concentration, to do that we know the material balance equation that is G s into y 1 by 1 minus y 1 minus y 2 by 1 minus y 2 would be equal to L s into x 1 divided by 1 minus x 1 minus x 2 divided 1 minus x 2. So, G s we know which is we have calculated 24.82 kilo mole per hour; L s which is given is 30000 k G per hour which is pure water is used as a no solvent.

So, it will be 30000 divided by 18 kilo mole per hour. So, this is essentially 1666.67 kilo mole per hour; y 1 which is the entering feed gas is shown mole fraction is 0.15 and no y 2 to is 0.0088 and also it is given that know the feed which is coming feed liquid solvent is free of sulphur dioxide.

So, x 2 would be 0, now if you substitute all these values in these equations. So, putting this values x 1 is equal to 0.00249, this is a concentration of sulphur dioxide in the exit stream; the exit stream of liquid.

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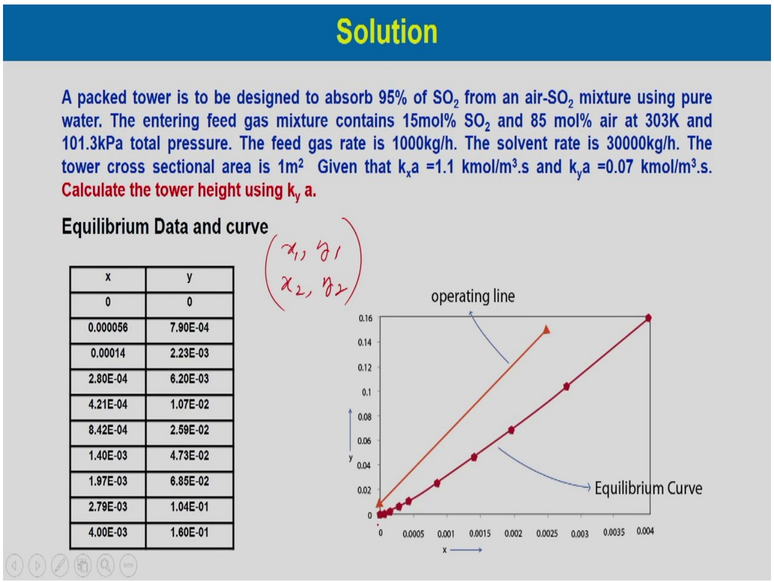

Solution

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Equilibrium Data and curve

$(x_1, y_1$
$x_2, y_2)$

x	y
0	0
0.000056	7.90E-04
0.00014	2.23E-03
2.80E-04	6.20E-03
4.21E-04	1.07E-02
8.42E-04	2.59E-02
1.40E-03	4.73E-02
1.97E-03	6.85E-02
2.79E-03	1.04E-01
4.00E-03	1.60E-01

So, now we have the equilibrium data. So, we can plot the equilibrium line and with the no data we have obtained that is x 1 and y 1 and x 2 and y 2 this with this data no data set we can plot the operating line. So, we know the all the no points and we can just join the terminal points. So, then we can obtain the operating line curve.

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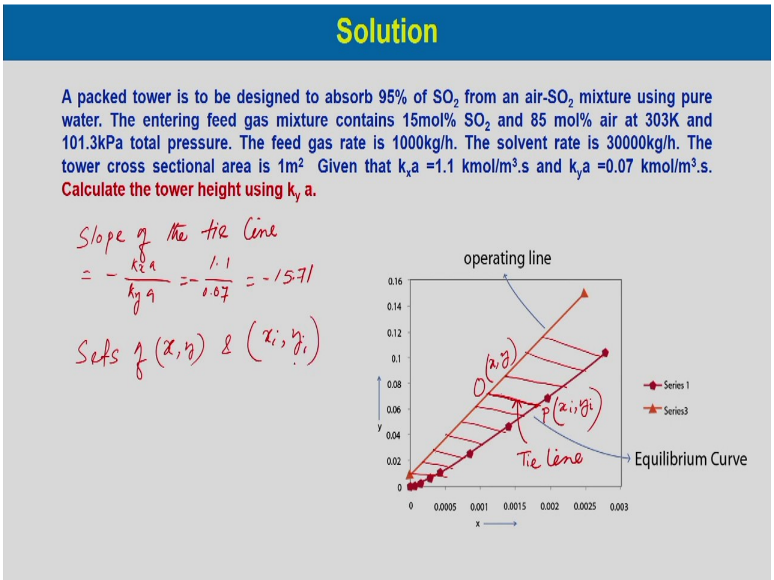

Solution

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Slope of the tie line

$$= -\frac{k_x a}{k_y a} = -\frac{1.1}{0.07} = -15.71$$

Sets of (x, y) & (x_i, y_i)

Now, equilibrium curve and operating line curve are known to us we have to draw the tie line. So, to draw the tie line we need to find out the slope of the tie line slope of the tie line, is we have define is equal to minus k x a divided by k y a. So, this values are given k x a is 1.1 kilo mole per metre cube second so1.1 x 1 divided by 0.07. So, which is equal to minus 15.71. So, with this a no say you consider a point somewhere at no P, which is no x i y i and you with this slope you can draw the no the tie line.

So, this is point say O with x and y. So, with no different you know if this these are parallel no (Refer Time: 35:55) no straight line a with this slope we can draw the no several tie line with no parallel to this one, with this slope. So, from this we will have a sets of x y and x i y i.

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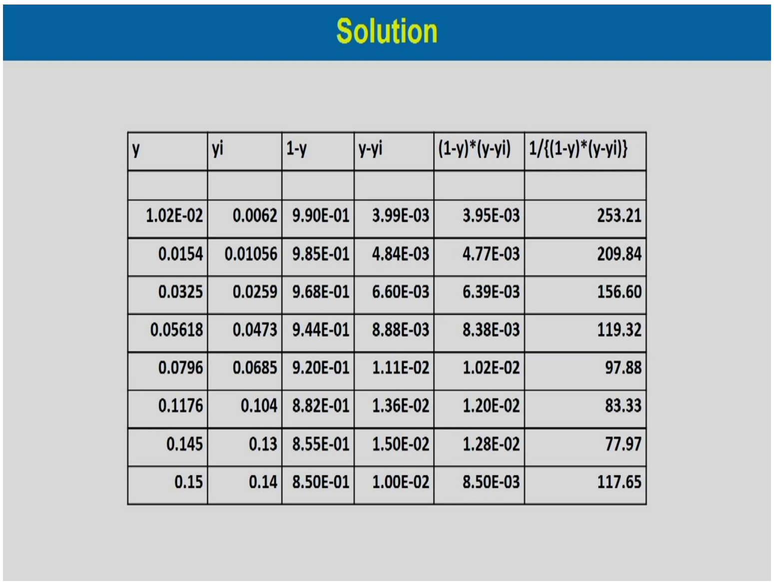

Solution

y	yi	1-y	y-yi	(1-y)*(y-yi)	1/{(1-y)*(y-yi)}
1.02E-02	0.0062	9.90E-01	3.99E-03	3.95E-03	253.21
0.0154	0.01056	9.85E-01	4.84E-03	4.77E-03	209.84
0.0325	0.0259	9.68E-01	6.60E-03	6.39E-03	156.60
0.05618	0.0473	9.44E-01	8.88E-03	8.38E-03	119.32
0.0796	0.0685	9.20E-01	1.11E-02	1.02E-02	97.88
0.1176	0.104	8.82E-01	1.36E-02	1.20E-02	83.33
0.145	0.13	8.55E-01	1.50E-02	1.28E-02	77.97
0.15	0.14	8.50E-01	1.00E-02	8.50E-03	117.65

Once this datas are known we can just calculate the y i values and y values and we can calculate 1 minus y then y minus y i and then 1 minus y into y minus y i and then 1 by 1 minus y into y minus y i. So, these values we can calculate ones we know these values this table we can generate with the tie line values.

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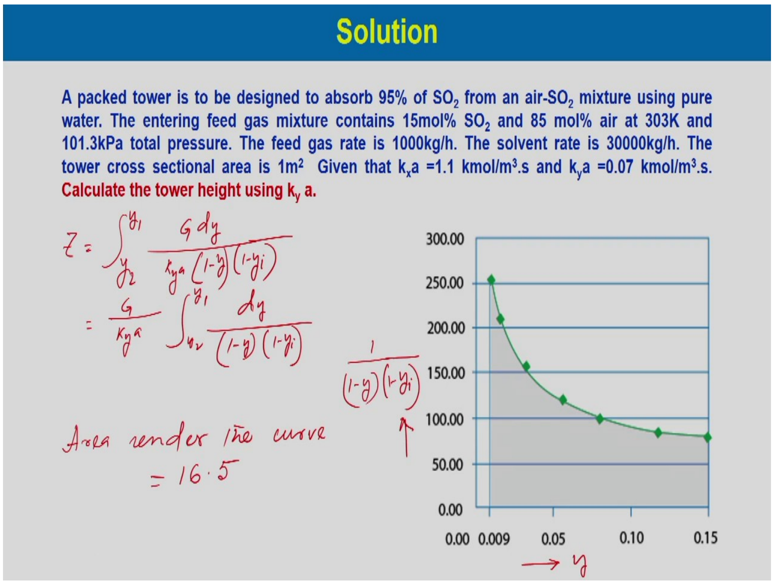

Solution

A packed tower is to be designed to absorb 95% of SO_2 from an air-SO_2 mixture using pure water. The entering feed gas mixture contains 15mol% SO_2 and 85 mol% air at 303K and 101.3kPa total pressure. The feed gas rate is 1000kg/h. The solvent rate is 30000kg/h. The tower cross sectional area is 1m² Given that k_xa =1.1 kmol/m³.s and k_ya =0.07 kmol/m³.s. Calculate the tower height using k_y a.

$$Z = \int_{y_2}^{y_1} \frac{G\,dy}{k_{ya}(1-y)(1-y_i)}$$

$$= \frac{G}{k_{ya}} \int_{y_2}^{y_1} \frac{dy}{(1-y)(1-y_i)}$$

Area under the curve = 16.5

Now you can plot with the equation we know for the calculating the height of the tower is z is equal to integral y 2 to y 1 G d y divided by k y a into 1 minus y into 1 minus y i. So, G by k y a integral y 2 to y 1 d y by 1 minus y into 1 minus y i.

Now, if we plot here in this figure this is y axis and this is x axis, x axis is y and y axis is no 1 by 1 minus y into 1 minus y i. So, if we plot with the data with the limit we have for x 1 y 1 and x 2 y 2 we can get this graph and then we can calculate the area under the curve. So, if you do, any method if you apply to find out the area under the curve many methods you have learnt the trapezoidal rule Simpson's one-third rule Simpson's five-fifth eighth rules.

So, there are different rules available to calculate the area under the curve you can use either one of them and (Refer Time: 39:04), looking into the pattern of the plot. So, you can calculate the area under the curve which would be typically know if you calculate for this it would be 16.5.

So, we know the values of this integral, we have to calculate G, we will take the average values of G because it is changing because of the solute transfer. So, we will consider here the average values of G, k y a is given. So, we can calculate the height of the tower.

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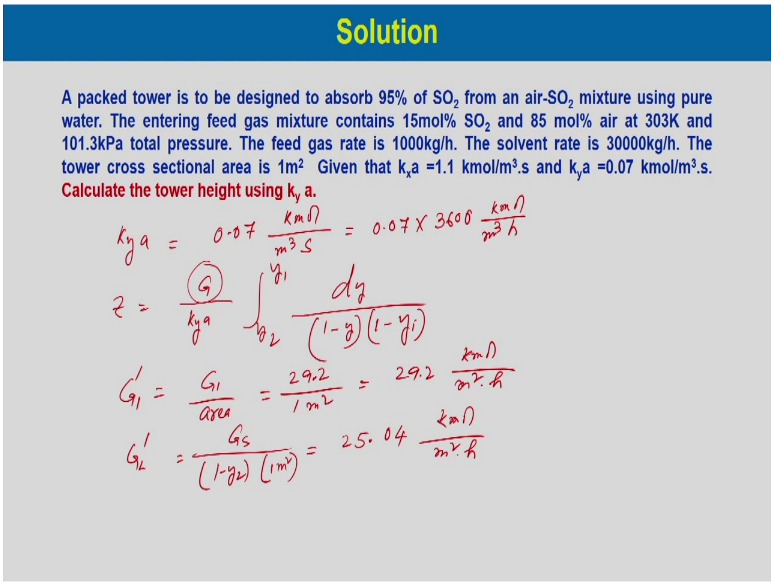

Solution

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$$k_y a = 0.07 \frac{kmol}{m^3 s} = 0.07 \times 3600 \frac{kmol}{m^3 h}$$

$$z = \frac{\boxed{G}}{k_y a} \int_{y_2}^{y_1} \frac{dy}{(1-y)(1-y_i)}$$

$$G_1' = \frac{G_1}{area} = \frac{29.2}{1\, m^2} = 29.2 \frac{kmol}{m^2 . h}$$

$$G_2' = \frac{G_s}{(1-y_2)(1 m^2)} = 25.04 \frac{kmol}{m^2 . h}$$

So, k y a over here; k y a is 0.07 k mole per metre cube second. So, this we can just multiply with 3600 kilo mole per metre cube hour in this equation z is equal to G by k y a integral y 2 to y 1 d y divided by 1 minus y into 1 minus y i we need to calculate G.

So, G 1 dash would be G 1 divided by area which is 29.2 divided by 1 meter square which is 29.2 kilo mole per metre square hour. And G 2 dash would be equal to G s by 1 minus y 2 into 1 meter square, which is equal to 25.04 kilo mole per metre square hour. Ok So, now, G 1 and G 2 we have G 2 dash we have calculated and we will take the average of this 2.

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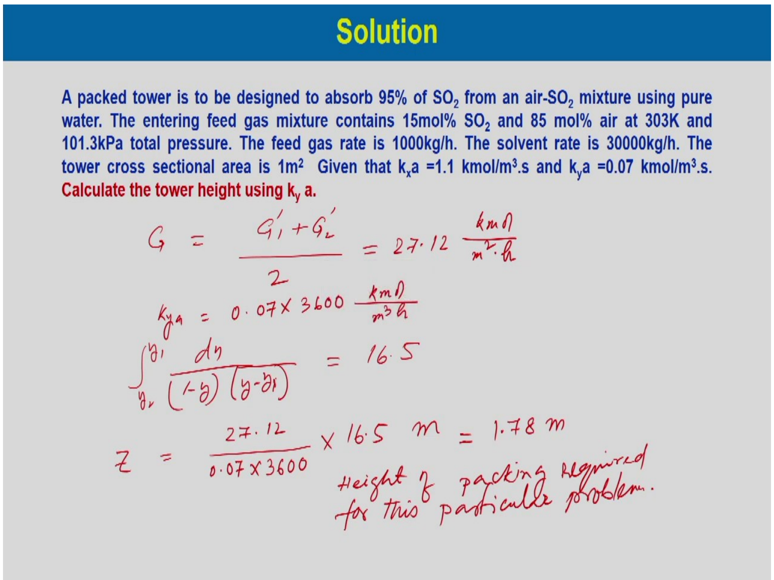

Solution

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$$G = \frac{G_1' + G_2'}{2} = 27.12 \ \frac{kmol}{m^2 \cdot h}$$

$$k_ya = 0.07 \times 3600 \ \frac{kmol}{m^3 h}$$

$$\int_{y_2}^{y_1} \frac{dy}{(1-y)(y-y_i)} = 16.5$$

$$Z = \frac{27.12}{0.07 \times 3600} \times 16.5 \ m = 1.78 \ m$$

Height of packing required for this particular problem.

So, G should be equal to G 1 plus G 2 dash G 1 dash by G 2 dash by 2 and if we substitute that it will be 27.12 kilo mole per metre square hour. So, k y a is 0.07 into 3600 kilo mole per metre cube hour area under the curve that is integral y 2 to y 1 d y 1 minus y into y minus y 1.

So, which is equal to no 16.5. So, we can calculate z by putting the values of G dash 27.12 divided by 0.07 into 3600 into 16.5 metre. So, if we calculate this would be about 1.78 metre. So, this is the no height of packing required for this particular problem.

So, we have seen how to know design based on the no individual mass transfer coefficient method and we calculated the height of packing required for a given separation. Considering different parameters to calculate the interfacial concentration how to obtain tie line and then how to plot it how to get the sets of data to plot the area, under the curve and we obtain finally, the height of the packing. We have discussed in detail.

Thank you for attending this lecture and we will continue our design of packed towers with different other methods to find out the height of the packing.