Mass Transfer Operations -I

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Lecture - 24

Height Equivalent to a Theoretical Plate (HETP), Design of packed column absorber for dilute and concentrated gases

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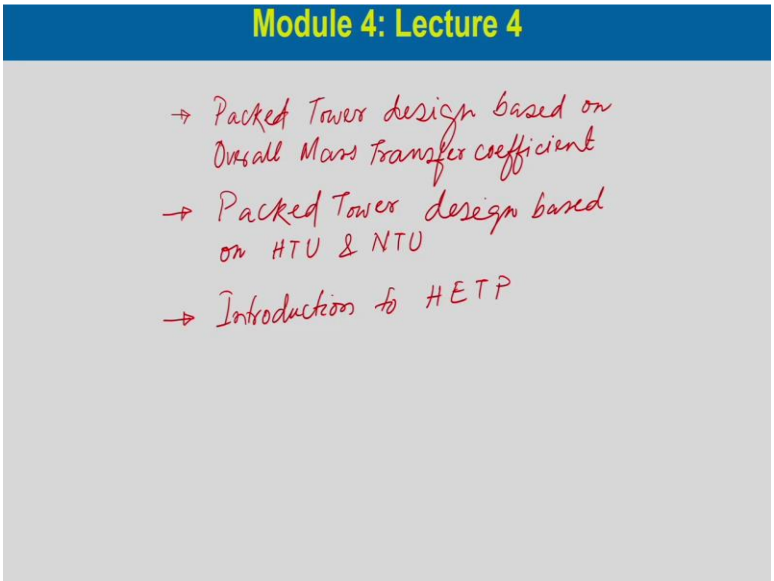

Module 4: Lecture 4

→ Packed Tower design based on Overall Mass Transfer coefficient

→ Packed Tower design based on HTU & NTU

→ Introduction to HETP

Welcome to the 4th lecture of module 4 on Mass Transfer Operation. In this module, we are discussing absorption mass transfer. In our last lecture, we consider three important thing for design of packed towers. So, we have considered first thing is the packed tower design based on overall mass transfer coefficient method.

The second thing, we have considered here is the packed tower design based on HTU and NTU, Height of Transfer Unit and Number of Transfer Unit method. The third thing we have considered is introduction to HETP-Height Equivalent to a Theoretical Plate that is design of packed towers based on height equivalent to a theoretical plate.

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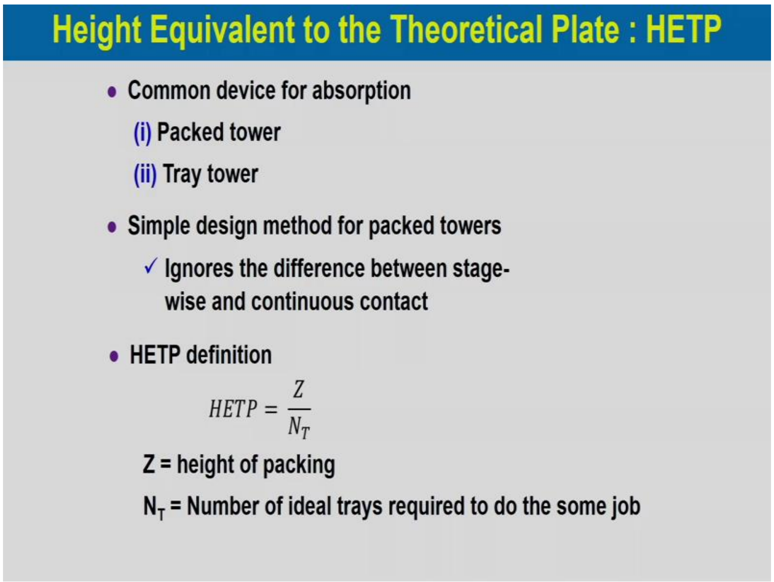

Height Equivalent to the Theoretical Plate : HETP

- Common device for absorption
  (i) Packed tower
  (ii) Tray tower
- Simple design method for packed towers
  ✓ Ignores the difference between stage-wise and continuous contact
- HETP definition

$$HETP = \frac{Z}{N_T}$$

Z = height of packing

N_T = Number of ideal trays required to do the some job

So, in this lecture, we will continue our discussion on HETP method. And then we will discuss the different cases for the dilute solution and the concentrated solution for packed tower design. So, height equivalent to the theoretical plate that is HETP, as you know there are two common device for the absorption process. They are packed towers, and tray towers.

The simple design method for packed towers, which ignores the difference between the stage wise and continuous contact, so that is the initial very simple design method which was proposed is the HETP method. And HETP height equivalent to a theoretical plate is defined is equal to Z by N T. Here Z is the height of packing required to do the same job divided by the number of ideal trays required to do the same job ok. So, H is the height of packing required to carry out a particular job, and N T is the number of ideal trays required to do the same job. So, HETP can be defined HETP equal to Z by N T.

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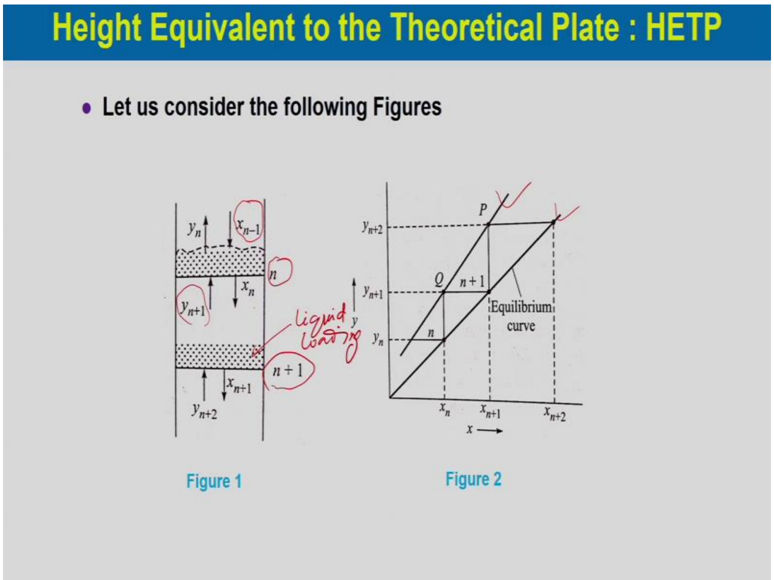

Height Equivalent to the Theoretical Plate : HETP

- Let us consider the following Figures

Figure 1

Figure 2

Now, let us consider these two figures. You can see the two stages are shown over here is stage n, and then here stage n plus 1. And this is the liquid on a particular tray liquid loading on a particular tray. So, the nomenclature over here, you can see for nth plate the exiting streams are x n and y n. So, y n is the vapour which is going off, x n is the liquid which is coming down from a particular tray and then the vapour which is entering in tray n each y n plus 1, which is coming from the previous tray.

And similarly, the liquid which is coming to this tray from the upper tray is x n minus 1. So, x n minus 1, and y n plus 1 is the entering gas and liquid composition. Similarly, you can see the compositions for tray n plus 1. And this is the operating line, and this is the equilibrium line for a particular system, and they are plotted over here.

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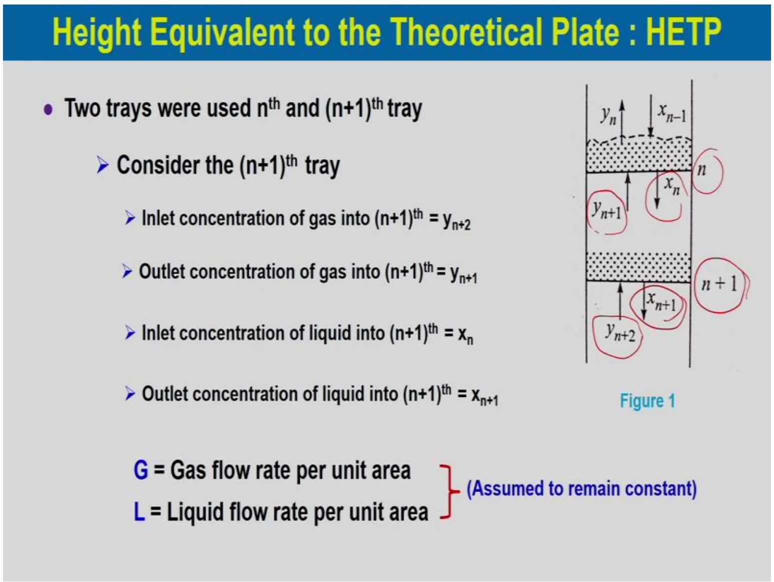

Height Equivalent to the Theoretical Plate : HETP

- Two trays were used nth and (n+1)th tray
  - Consider the (n+1)th tray
    - Inlet concentration of gas into (n+1)th = y_{n+2}
    - Outlet concentration of gas into (n+1)th = y_{n+1}
    - Inlet concentration of liquid into (n+1)th = x_n
    - Outlet concentration of liquid into (n+1)th = x_{n+1}

Figure 1

G = Gas flow rate per unit area
L = Liquid flow rate per unit area
(Assumed to remain constant)

And now if we consider tray n plus 1, so we have considered two trays; one is nth tray, another is n plus 1 tray. So, in this two tray, now consider the n plus 1th tray. So, if we consider n plus 1th tray, now the inlet concentration of the gas to this tray n plus 1th tray is y n plus 2. And then outlet concentration of the gas into n plus 1th tray is know y n plus 1, which is exiting to this tray.

Similarly, inlet concentration of the liquid n plus 1th tray is x n which is over here is coming to this tray. And then outlet concentration of the liquid from this tray is x n plus 1 over here. Now, gas flow rate per unit area is G, and L is the liquid flow rate per unit area. This is assume to be remain constant.

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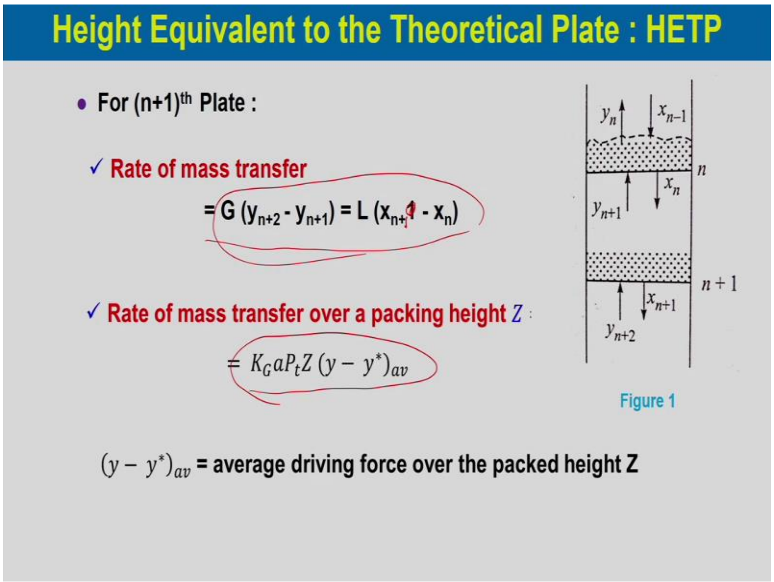

Height Equivalent to the Theoretical Plate : HETP

- For $(n+1)^{th}$ Plate :
  - ✓ Rate of mass transfer

    $= G(y_{n+2} - y_{n+1}) = L(x_{n+1} - x_n)$

  - ✓ Rate of mass transfer over a packing height Z :

    $= K_G a P_t Z (y - y^*)_{av}$

$(y - y^*)_{av}$ = average driving force over the packed height Z

Figure 1

Now, for n plus 1th plate if we do the you know mass balance equation, and rate of mass transfer we can write G into y n plus 2 minus y n plus 1 would be equal to L into x n plus 1 minus x n. Then the rate of mass transfer over a packing height Z, we know that is equal to K G a P t Z y minus y star average. So, this is the mass transfer for a particular plate rate of mass transfer, we can do the balance equation overall balance equation, and for that particular plate. And for the packing height Z, we can write the you know mass transfer rate over that packing, this is packed towers, and this is for the plate towers. So, y minus y star average is the average driving force over the packing height Z. Now, these two rate we can give equivalent so or equal.

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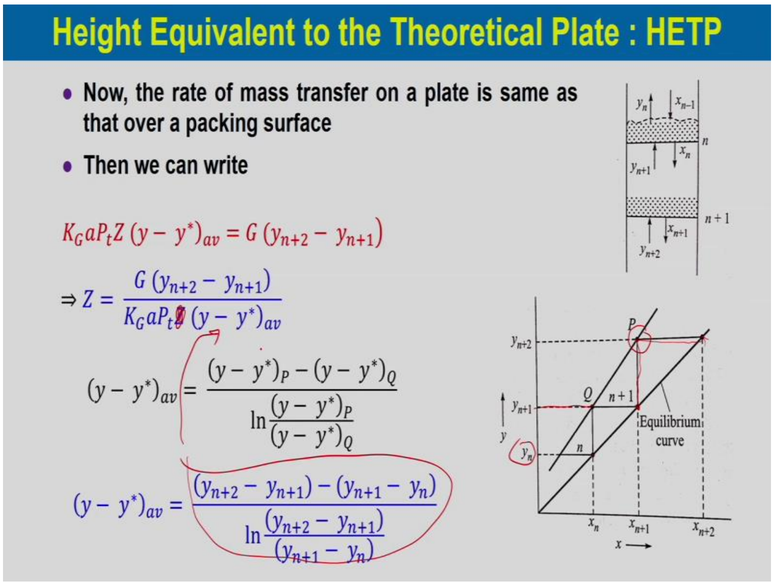

Height Equivalent to the Theoretical Plate : HETP

- Now, the rate of mass transfer on a plate is same as that over a packing surface
- Then we can write

$$K_G a P_t Z (y - y^*)_{av} = G(y_{n+2} - y_{n+1})$$

$$\Rightarrow Z = \frac{G(y_{n+2} - y_{n+1})}{K_G a P_t (y - y^*)_{av}}$$

$$(y - y^*)_{av} = \frac{(y - y^*)_P - (y - y^*)_Q}{\ln \frac{(y - y^*)_P}{(y - y^*)_Q}}$$

$$(y - y^*)_{av} = \frac{(y_{n+2} - y_{n+1}) - (y_{n+1} - y_n)}{\ln \frac{(y_{n+2} - y_{n+1})}{(y_{n+1} - y_n)}}$$

Then we can write, now the rate of mass transfer on a plate is same as that of over a packing surface, so that is what we define HETP. Then we can write K G a P t Z into y minus y star average would be equal to G y n plus 2 minus y n plus 1. So, from here we can just write the height of packing required is Z would be equal to G y n plus 2 minus y n plus 1 divided by K G a P t y minus y star average.

And y minus y star average from this equilibrium curve and the operating line curve for a plate column, we can write y minus y star P minus y minus y star Q at this location divided by ln y minus y star P by y minus y star Q. Now, this y minus y star P at location P over here, it would be y n plus 2, and its equilibrium concentration which is over here is y n plus 1 minus y n plus 1 this one, and the equilibrium composition y n. So, y n plus 1 minus y n that is at Q divided by ln y n plus 2 minus y n plus 1 divided by y n plus 1 minus y n. So, we can substitute this relation over y minus y average, so y minus y average, if we substitute this equation.

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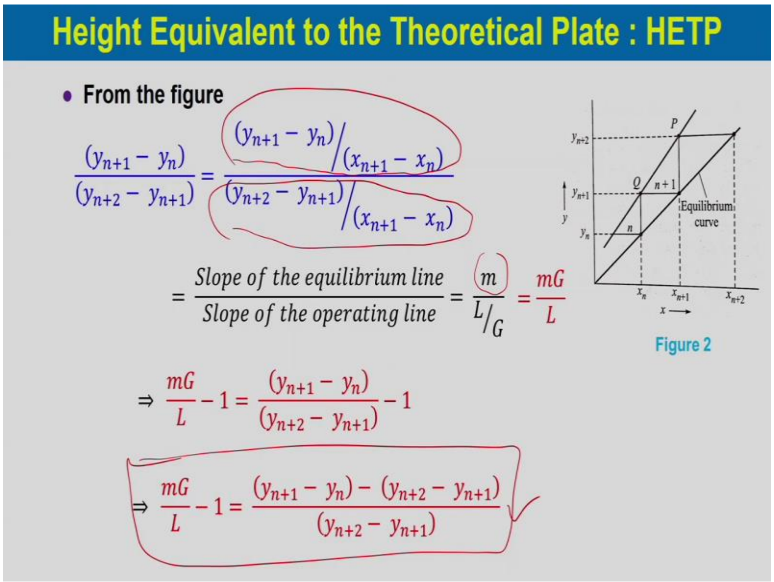

Height Equivalent to the Theoretical Plate : HETP

- From the figure

$$\frac{(y_{n+1}-y_n)}{(y_{n+2}-y_{n+1})} = \frac{(y_{n+1}-y_n)/(x_{n+1}-x_n)}{(y_{n+2}-y_{n+1})/(x_{n+1}-x_n)}$$

$$= \frac{\textit{Slope of the equilibrium line}}{\textit{Slope of the operating line}} = \frac{m}{L/G} = \frac{mG}{L}$$

$$\Rightarrow \frac{mG}{L}-1 = \frac{(y_{n+1}-y_n)}{(y_{n+2}-y_{n+1})}-1$$

$$\boxed{\Rightarrow \frac{mG}{L}-1 = \frac{(y_{n+1}-y_n)-(y_{n+2}-y_{n+1})}{(y_{n+2}-y_{n+1})}}$$

Figure 2

Then from the figure we can write y n plus 1 minus y n divided by y n plus 2 minus y n plus 1 would be equal to, if we just divide the both numerator and the denominator by x n plus 1 minus x n. So, similarly in the denominator here. So, this portion represents y n plus 1 minus y n divided by x n plus 1 minus x n is the slope of the equilibrium line divided by y n plus 2 minus y n plus 1 divided by x n plus 1 minus x n is the slope of the operating line.

Slope of the operating line, we have derived this part is L by G. And slope of the equilibrium line is m. So, m divided by L by G which is equal to mG by L, so this is we can get from this figure. Now, if we subtract both side with the know minus 1, so it will be mG by L minus 1 would be equal to y n plus 1 minus y n divided by y n plus 2 minus y n plus 1 minus 1.

Now, if we just simplify it, it will be mG by L minus 1 would be equal to y n plus 1 minus y n minus y n plus 2 minus y n plus 1 divided by y n plus 2 minus y n plus 1. So, we can get this relation by considering from the figure we can write this.

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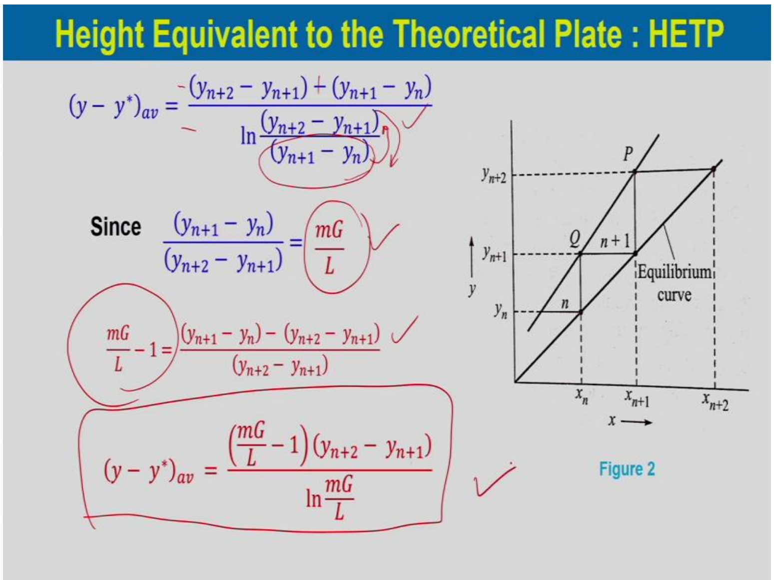

Height Equivalent to the Theoretical Plate : HETP

$$(y - y^*)_{av} = \frac{-(y_{n+2} - y_{n+1}) + (y_{n+1} - y_n)}{-\ln\frac{(y_{n+2} - y_{n+1})}{(y_{n+1} - y_n)}}$$

Since $\frac{(y_{n+1} - y_n)}{(y_{n+2} - y_{n+1})} = \frac{mG}{L}$

$$\frac{mG}{L} - 1 = \frac{(y_{n+1} - y_n) - (y_{n+2} - y_{n+1})}{(y_{n+2} - y_{n+1})}$$

$$\boxed{(y - y^*)_{av} = \frac{\left(\frac{mG}{L} - 1\right)(y_{n+2} - y_{n+1})}{\ln\frac{mG}{L}}}$$

Figure 2

And then we know y minus y average is this one, and this one is mG by L, and mG by L minus 1 is this one. So, these two relations we have obtained, and this is we have already obtained from the y minus y average from this figure. y minus y star average would be equal to if we substitute over here is mG by L minus 1 into y n plus 2 minus y n plus 1 divided by ln, this part we can write mG by L.

So, while doing so, if you take the negative of this and reverse it y n plus 1 minus y n would be upper part and this will be lower. So, you will have a negative sign, and if you take it negative, so this will be negative, and this will be positive. So, then you will have this relation by substituting this part, and this part you will obtain y minus y star average would be equal to mG by L minus 1 into y n plus 2 minus y n plus 1 divided by ln mG by L.

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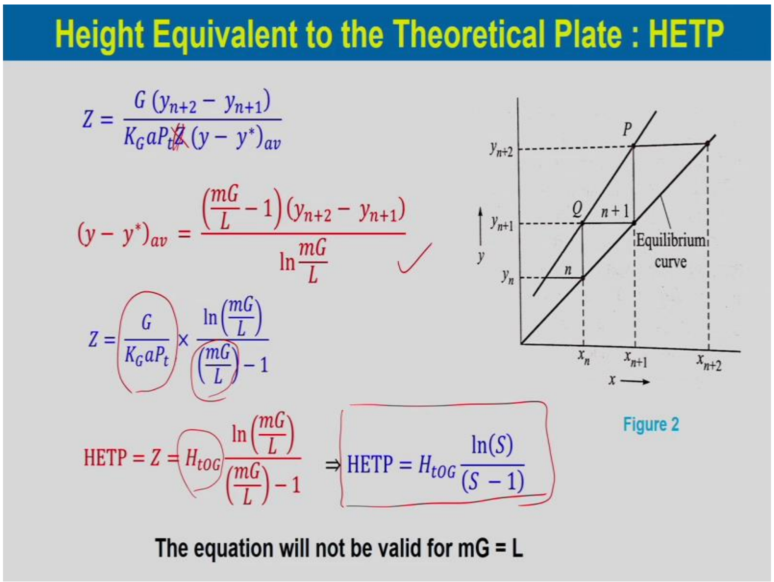

Height Equivalent to the Theoretical Plate : HETP

$$Z = \frac{G\,(y_{n+2} - y_{n+1})}{K_G a P_t \cancel{Z}\,(y - y^*)_{av}}$$

$$(y - y^*)_{av} = \frac{\left(\frac{mG}{L} - 1\right)(y_{n+2} - y_{n+1})}{\ln\frac{mG}{L}} \checkmark$$

$$Z = \frac{G}{K_G a P_t} \times \frac{\ln\left(\frac{mG}{L}\right)}{\left(\frac{mG}{L}\right) - 1}$$

$$\mathrm{HETP} = Z = H_{tOG}\frac{\ln\left(\frac{mG}{L}\right)}{\left(\frac{mG}{L}\right) - 1} \Rightarrow \boxed{\mathrm{HETP} = H_{tOG}\frac{\ln(S)}{(S - 1)}}$$

Figure 2

The equation will not be valid for mG = L

So, now if we substitute this in the design of the packed towers height design equation, it is G into y n plus 2 minus y n plus 1 divided by K G a P t y minus y star average. So, this y minus y star average is this one we have derived. And if we substitute over here, so you will have height of packing would be equal to G by K G a P t into ln mG by L divided by mG by L minus 1.

So, HETP which is Z is equal to this is H tOG into ln mG by L divided by mG by L minus 1. So, from here we can write HETP would be equal to H tOG ln S divided by S minus 1. So, mG by L is S, and this equation will not be valid for mG equal to L. So, if it is mG equal to L over here, so this equations will be undefined and will not be valid. So, this is the equation of HETP with respect to the stripping factor, and inverse is the absorption factor, we can calculate the height of the packing required. So, this is very simplified procedure for design of a packed towers.

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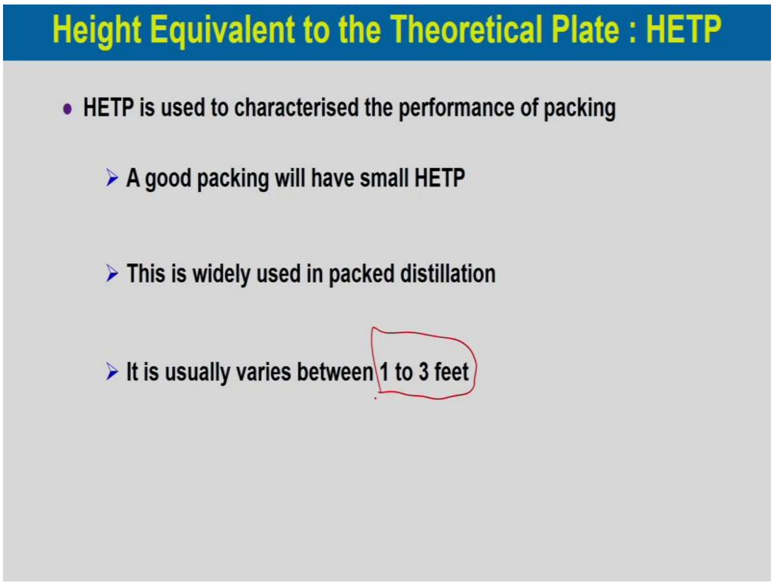

Height Equivalent to the Theoretical Plate : HETP

- HETP is used to characterised the performance of packing
  - A good packing will have small HETP
  - This is widely used in packed distillation
  - It is usually varies between 1 to 3 feet

So, HETP is used to characterise the performance of the packing. A good packing will have small HETP. And this is widely used in packed distillation. It is usually varies between 1 to 3 feet. So, HETP is the length of the packing required is varied between 1 to 3 feet for a particular job.

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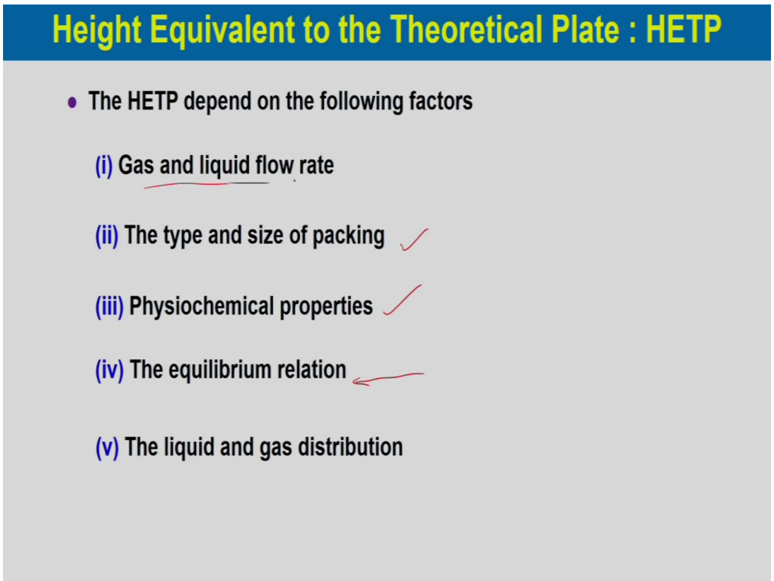

Height Equivalent to the Theoretical Plate : HETP

- The HETP depend on the following factors

(i) Gas and liquid flow rate
(ii) The type and size of packing
(iii) Physiochemical properties
(iv) The equilibrium relation
(v) The liquid and gas distribution

Now, HETP depends on the following factors. One is gas and liquid flow rate, the type and size of packing, the physicochemical properties, the equilibrium relation, and the liquid and gas distribution. So, these parameters are important for designing of the

HETP, because we have considered the linear equilibrium relations and physicochemical properties also important. Type and size of packing is also over important, and their distribution of the gas and liquid into the packing material is also important, and their flow rates.

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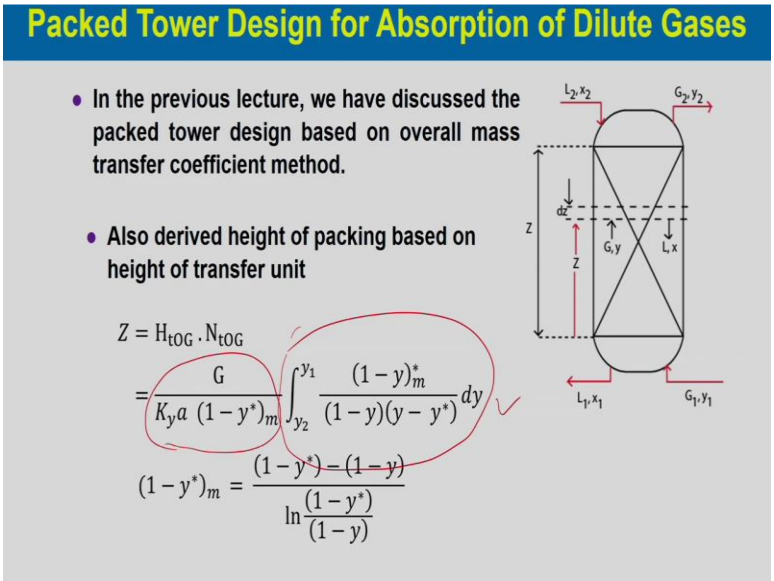

Packed Tower Design for Absorption of Dilute Gases

- In the previous lecture, we have discussed the packed tower design based on overall mass transfer coefficient method.
- Also derived height of packing based on height of transfer unit

$$Z = H_{tOG} . N_{tOG}$$

$$= \frac{G}{K_y a \, (1-y^*)_m} \int_{y_2}^{y_1} \frac{(1-y)_m^*}{(1-y)(y-y^*)} dy$$

$$(1-y^*)_m = \frac{(1-y^*)-(1-y)}{\ln \frac{(1-y^*)}{(1-y)}}$$

Now, we will consider the packed tower design for absorption of dilute gases. So, if we have a dilute gas, the design equations we have derived earlier for the know packed tower design based on number of transfer unit, and height of transfer unit, we can simplify for the dilute gases.

So, in our previous lecture, we have discussed the packed tower design based on overall mass transfer coefficient method. We have also derived height of packing based on HTU height of transfer unit. So, Z is equal to H tOG into N tOG, this is we have derived. And then for overall mass transfer coefficient, this is G divided by capital K y a into 1 minus y star m integral y 2 to y 1 1 minus y star m divided by 1 minus y into y minus y star dy. So, this is the design equation for height of packing.

And this part we call H tOG, and this part we call N tOG, because this is based on the overall know mass transfer coefficient in the gas phase. So, 1 minus y star m is basically 1 minus y star minus 1 minus y divided by ln 1 minus y star divided by 1 minus y, this is log min concentration gradient.

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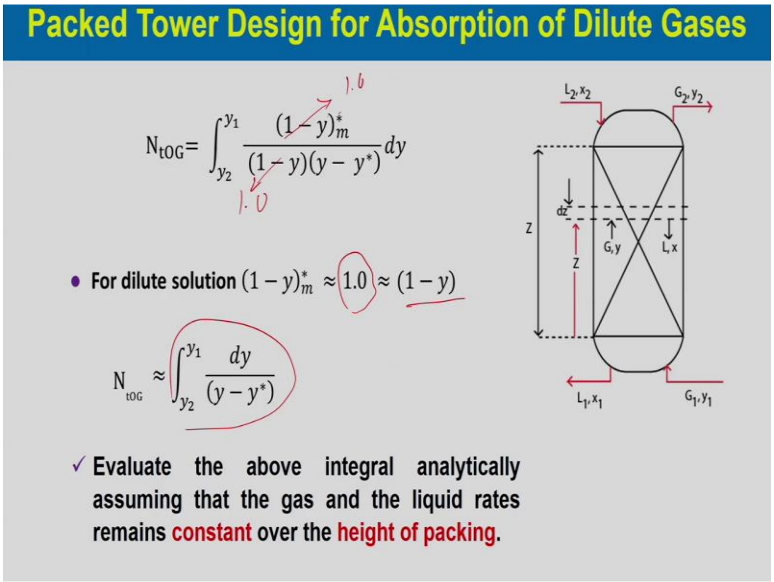

Packed Tower Design for Absorption of Dilute Gases

$$N_{tOG} = \int_{y_2}^{y_1} \frac{\overset{1.0}{\cancel{(1-y)^*_m}}}{\underset{1.0}{\cancel{(1-y)}}(y-y^*)}dy$$

- For dilute solution $(1-y)^*_m \approx \boxed{1.0} \approx \underline{(1-y)}$

$$N_{tOG} \approx \int_{y_2}^{y_1} \frac{dy}{(y-y^*)}$$

✓ Evaluate the above integral analytically assuming that the gas and the liquid rates remains constant over the height of packing.

Now, N tOG is this one this equation integral y 2 to y 1 1 minus y star m divided by 1 minus y into y minus y star dy. Now, if we consider the dilute gas, for dilute gas 1 minus y star m would be approximately equal to 1, which would be approximately equal to 1 minus y. So, if these both are same, then we N tOG we can simplify approximately equal to integral y 2 to y 1 dy by y minus y star, so this will be one.

And then and they are same. So, this N tOG would be equal to integral y 2 to y 1 dy divided by y minus y star. So, to evaluate the integral this integral analytically assuming that the gas and liquid flow rate constant over the height of packing. So, we can do the integration, and if you consider, there is no gas and liquid flow rate remains almost constant over the height of the packing.

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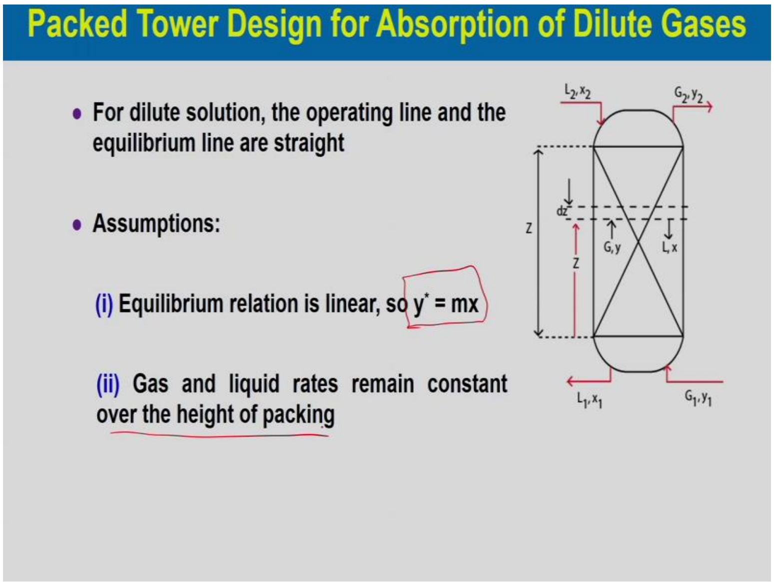

Packed Tower Design for Absorption of Dilute Gases

- For dilute solution, the operating line and the equilibrium line are straight
- Assumptions:

  (i) Equilibrium relation is linear, so $y^* = mx$

  (ii) Gas and liquid rates remain constant over the height of packing

So, for dilute solution, the operating line and the equilibrium lines are straight, because there is a very little solute transfer. So, assumptions here over is equilibrium relation is linear, so y star would be equal to mx linear equilibrium curve. And second thing is that gas and liquid rates remains constant over the height of packing.

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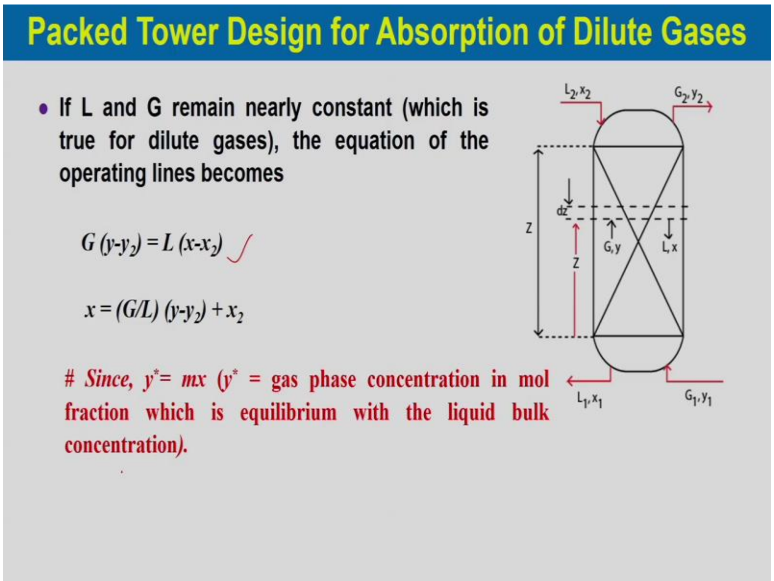

Packed Tower Design for Absorption of Dilute Gases

- If L and G remain nearly constant (which is true for dilute gases), the equation of the operating lines becomes

$$G\,(y-y_2) = L\,(x-x_2)$$

$$x = (G/L)\,(y-y_2) + x_2$$

 # Since, $y^* = mx$ (y^* = gas phase concentration in mol fraction which is equilibrium with the liquid bulk concentration).

Now, if L and G remains constant which is true for the dilute gases, the equation of the operating line, we can write G into y minus y star is equal to L into x minus x 2. So, the operating line equation, we can write G into y minus y 2 is equal to L into x minus x 2.

So, from here if we simplify, it would be x would be equal to G by L into y minus y 2 plus x 2. And since y star is equal to mx that is y star is the gas phase concentration in mole fraction unit is equilibrium with the liquid bulk concentration.

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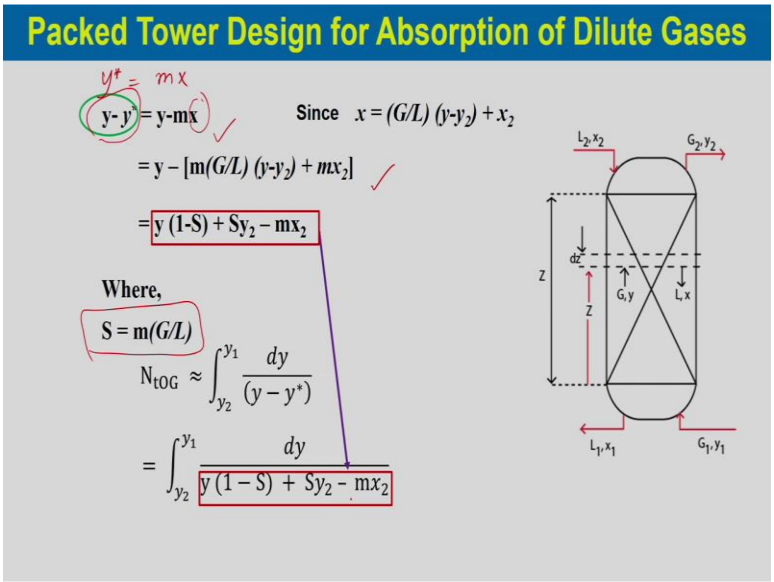

Packed Tower Design for Absorption of Dilute Gases

$y^* = mx$

$\boxed{y - y^*} = y - mx$ ✓ Since $x = (G/L)(y - y_2) + x_2$

$= y - [m(G/L)(y - y_2) + mx_2]$ ✓

$= \boxed{y(1-S) + Sy_2 - mx_2}$

Where,

$\boxed{S = m(G/L)}$

$$N_{tOG} \approx \int_{y_2}^{y_1} \frac{dy}{(y - y^*)}$$

$$= \int_{y_2}^{y_1} \frac{dy}{\boxed{y(1-S) + Sy_2 - mx_2}}$$

So, in that case we can write y minus y star is equal to y minus mx. So, basically y star is equal to m x. So, in this equation, if we add both the side know this if we subtract from y in the left hand side as well as on the right hand side, you will get y minus y star would be equal to y minus mx. Now, since x is equal to you have seen from the operating line equation x is equal to G by L y minus y 2 plus x 2.

Now, if we substitute in place of x here, so you will obtain y minus m into G by L y minus y 2 plus mx 2. So, mG by L is S, so we can write y into 1 minus S plus S y 2 minus mx 2. Here S is m G by L. This is the equation; it is y 2 to y 1 dy by y minus y star, so we obtain this y minus y 2 and y into 1 minus S plus S y 2 minus mx 2. So, if we substitute here in this y minus y star over here, so you will have know N tOG would be equal to integral y 2 to y 1 dy divided by y 1 minus S plus S y 2 minus mx 2.

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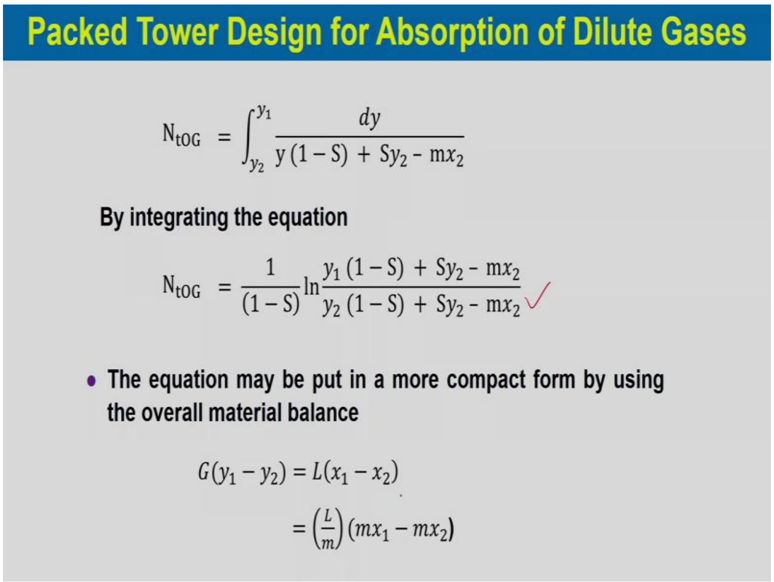

Packed Tower Design for Absorption of Dilute Gases

$$N_{tOG} = \int_{y_2}^{y_1} \frac{dy}{y(1-S) + Sy_2 - mx_2}$$

By integrating the equation

$$N_{tOG} = \frac{1}{(1-S)} \ln \frac{y_1(1-S) + Sy_2 - mx_2}{y_2(1-S) + Sy_2 - mx_2} ✓$$

- The equation may be put in a more compact form by using the overall material balance

$$G(y_1 - y_2) = L(x_1 - x_2)$$

$$= \left(\frac{L}{m}\right)(mx_1 - mx_2)$$

So, this is the design equation. And now if we integrate, so you will obtain N tOG would be equal to 1 by 1 minus S ln y 1 into 1 minus S plus Sy 2 minus mx 2 divided by y 2 into 1 minus S plus S y 2 minus m x 2. The equation may be put in a more compact form by using the overall material balance equation. So, this is the overall material balance equation G in to y 1 minus y 2 would be equal to L into x 1 minus x 2. And this L by m if we just multiply denominator and the numerator with m, so this part would be L by m into m x 1 minus m x 2.

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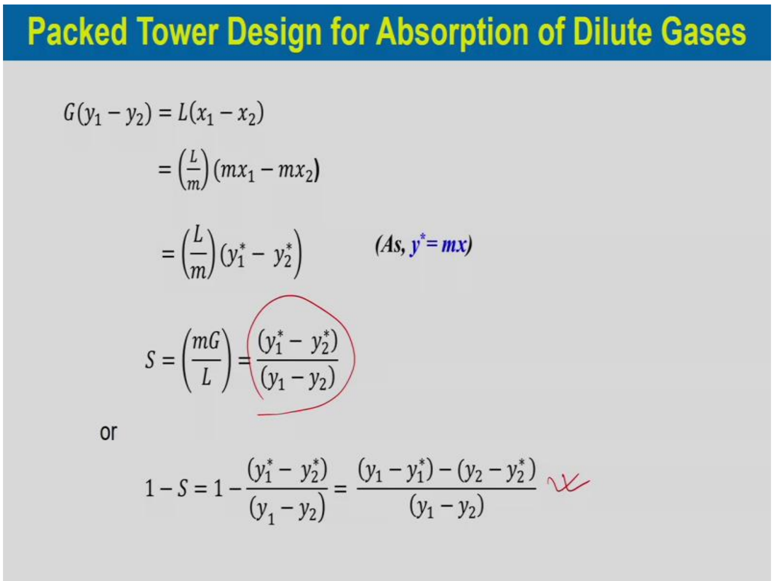

Packed Tower Design for Absorption of Dilute Gases

$$G(y_1 - y_2) = L(x_1 - x_2)$$

$$= \left(\frac{L}{m}\right)(mx_1 - mx_2)$$

$$= \left(\frac{L}{m}\right)(y_1^* - y_2^*) \qquad (As,\ y^* = mx)$$

$$S = \left(\frac{mG}{L}\right) = \frac{(y_1^* - y_2^*)}{(y_1 - y_2)}$$

or

$$1 - S = 1 - \frac{(y_1^* - y_2^*)}{(y_1 - y_2)} = \frac{(y_1 - y_1^*) - (y_2 - y_2^*)}{(y_1 - y_2)} ✓$$

And now if we substitute from the equilibrium relation, so mx 1 is y 1 star minus mx 2 is the y 2 star, as y star is equal to mx So, S we can write S is equal to mG by L, so it would be y 1 star minus y 2 star divided by y 1 minus y 2 so or we can write 1 minus S would be 1 minus this part. And so it will be 1 minus S would be equal to y 1 minus y 1 star minus y 2 minus y 2 star divided by y 1 minus y 2.

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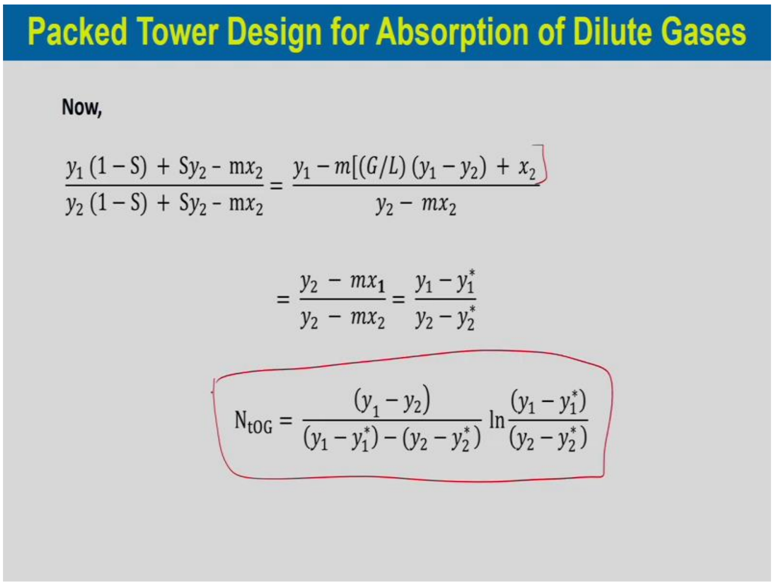

Packed Tower Design for Absorption of Dilute Gases

Now,

$$\frac{y_1(1-S) + Sy_2 - mx_2}{y_2(1-S) + Sy_2 - mx_2} = \frac{y_1 - m[(G/L)(y_1 - y_2) + x_2]}{y_2 - mx_2}$$

$$= \frac{y_2 - mx_1}{y_2 - mx_2} = \frac{y_1 - y_1^*}{y_2 - y_2^*}$$

$$\boxed{N_{tOG} = \frac{(y_1 - y_2)}{(y_1 - y_1^*) - (y_2 - y_2^*)} \ln\frac{(y_1 - y_1^*)}{(y_2 - y_2^*)}}$$

So, if we do the mathematical manipulation, so you will obtain this relation y 1 into 1 minus S plus Sy 2 minus mx 2 divided by y 2 into 1 minus S plus Sy 2 minus mx 2 would be equal to y 1 minus m G by L y 1 minus y 2 plus x 2 divided by know y 2 minus mx 2. So, from here we can write y 2 minus mx 1 divided by y 2 minus mx 2 would be equal to y 1 minus y 1 star divided by y 2 minus y 2 star. And hence N Tog, you will obtain is equal to y 1 minus y 2 divided by y 1 minus y 1 star minus y 2 minus y 2 star into ln y 1 minus y 1 star divided by y 2 minus y 2 star. So, this is the equations of N tOG you can obtain.

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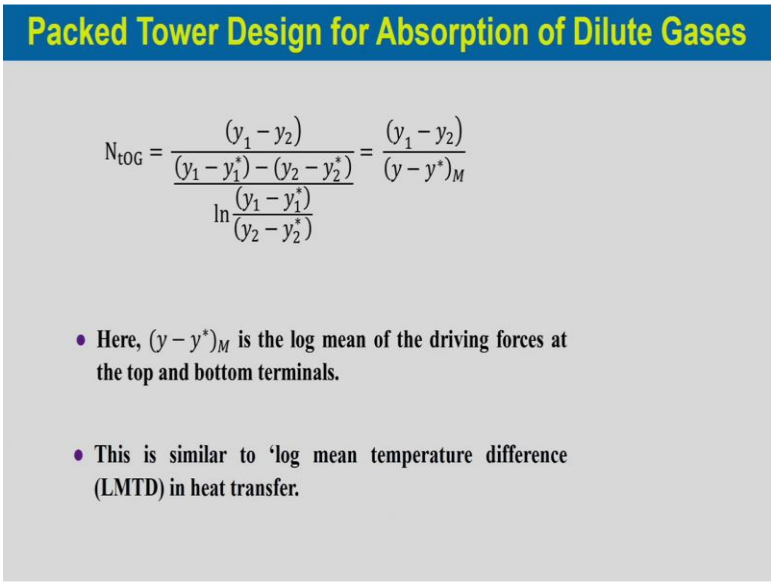

Packed Tower Design for Absorption of Dilute Gases

$$N_{tOG} = \frac{(y_1 - y_2)}{\dfrac{(y_1 - y_1^*) - (y_2 - y_2^*)}{\ln\dfrac{(y_1 - y_1^*)}{(y_2 - y_2^*)}}} = \frac{(y_1 - y_2)}{(y - y^*)_M}$$

- **Here, $(y - y^*)_M$ is the log mean of the driving forces at the top and bottom terminals.**
- **This is similar to 'log mean temperature difference (LMTD) in heat transfer.**

The overall equation for N tOG, we can write in this form which is equal to y 1 minus y 2 divided by y minus y star M. So, y minus y star M is the log mean driving force at top and bottom terminals. So, this is similar to log min temperature gradient LMTD in heat transfer.

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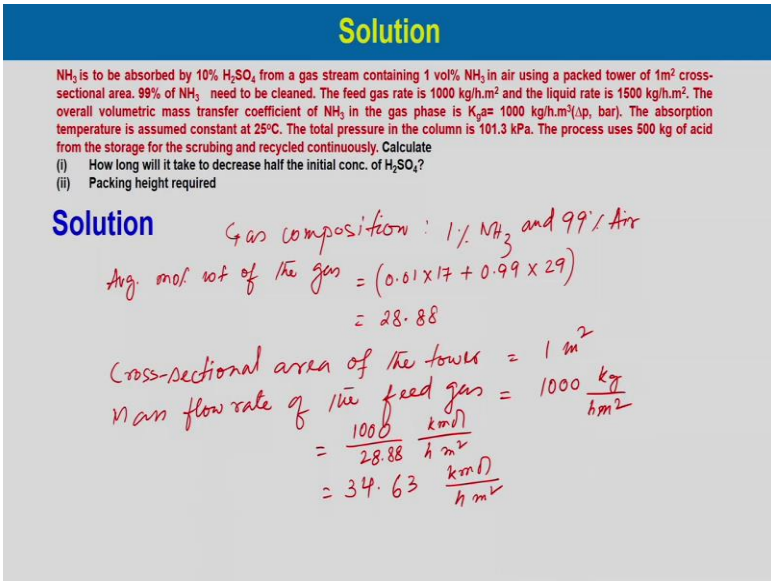

Solution

NH_3 is to be absorbed by 10% H_2SO_4 from a gas stream containing 1 vol% NH_3 in air using a packed tower of $1 m^2$ cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 1000 kg/h.m^2 and the liquid rate is 1500 kg/h.m^2. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is K_ga= 1000 kg/h.m^3(Δp, bar). The absorption temperature is assumed constant at 25°C. The total pressure in the column is 101.3 kPa. The process uses 500 kg of acid from the storage for the scrubing and recycled continuously. Calculate

(i) How long will it take to decrease half the initial conc. of H_2SO_4?

(ii) Packing height required

Solution

Gas composition : 1% NH_3 and 99% Air

Avg. mol. wt of the gas $= (0.01 \times 17 + 0.99 \times 29)$

$= 28.88$

Cross-sectional area of the tower $= 1\ m^2$

Mass flow rate of the feed gas $= 1000\ \frac{kg}{h m^2}$

$= \frac{1000}{28.88}\ \frac{kmol}{h\ m^2}$

$= 34.63\ \frac{kmol}{h\ m^2}$

Now, let us take an example to solve our process, where considered a dilute gas absorption. Here ammonia is to be absorbed by 10 percent sulphuric acid from a gas streams containing 1 volume percent ammonia in air using a packed towers of 1 meter square cross-sectional area. And 99 percent of ammonia need to be cleaned. The feed gas rate is 1000 kg per hour meter square, and the liquid rate is 1500 kg per hour meter square.

The overall volumetric mass transfer coefficient of ammonia in the gas phase kg a would be equal to 1000 kg per hour meter cube into delta P in bar. The absorption temperature is assumed constant at 25 degree centigrade. The total pressure in the column is 101.3 kilopascal. The process uses 500 kg of acid from a storage for the scrubbing and recycling continuously. Now, we need to calculate, how long will it take to decrease half the initial concentration of H 2 SO 4, and the packing height required.

Now, let us solve this problem the parameters which are given is the gas composition is know 1 percent ammonia, and 99 percent air. So, average molecular weight of the gas is equal to 0.01 into 17 is the molecular weight of ammonia plus 0.99 into the molecular weight of air 29. So, this would be know equal to 28.88.

Now, the cross-sectional area of the tower is equal to 1 meter square which is given. Mass flow rate of the feed gas is given, so mass flow rate of the feed gas is equal to 1000 kg per hour meter square, so which is equal to 1000 by 28.88 which is the average molecular weight of the feed gas is k mole per hour meter square. And it is about 34.63 k mole per hour meter square. So, we have calculated the average molecular weight and then mass flow rate of the feed in terms of kilo mole per hour meter square.

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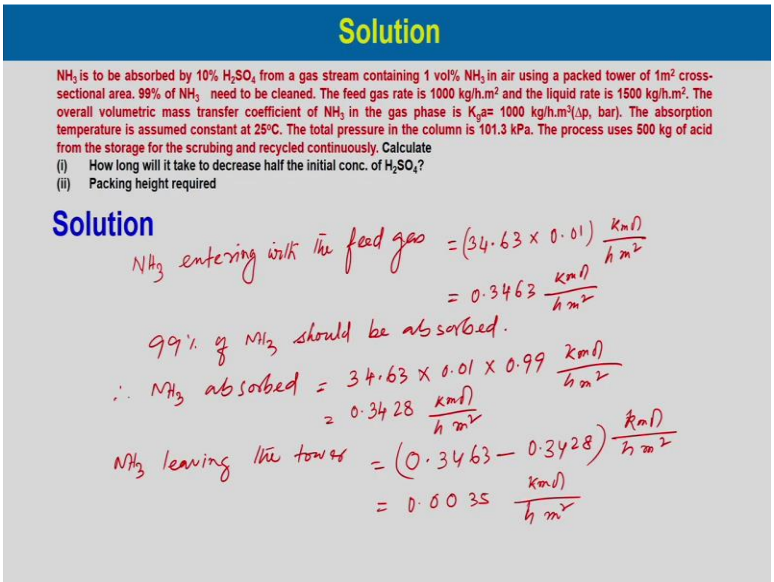

Solution

NH_3 is to be absorbed by 10% H_2SO_4 from a gas stream containing 1 vol% NH_3 in air using a packed tower of $1 m^2$ cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 1000 $kg/h.m^2$ and the liquid rate is 1500 $kg/h.m^2$. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is $K_g a = 1000\ kg/h.m^3(\Delta p,\ bar)$. The absorption temperature is assumed constant at 25°C. The total pressure in the column is 101.3 kPa. The process uses 500 kg of acid from the storage for the scrubing and recycled continuously. Calculate

(i) How long will it take to decrease half the initial conc. of H_2SO_4?
(ii) Packing height required

Solution

NH_3 entering with the feed gas $= (34.63 \times 0.01) \frac{Kmol}{h\,m^2}$

$= 0.3463 \frac{Kmol}{h\,m^2}$

99% of NH_3 should be absorbed.

$\therefore$ NH_3 absorbed $= 34.63 \times 0.01 \times 0.99 \frac{Kmol}{h\,m^2}$

$= 0.3428 \frac{Kmol}{h\,m^2}$

NH_3 leaving the tower $= (0.3463 - 0.3428) \frac{Kmol}{h\,m^2}$

$= 0.0035 \frac{Kmol}{h\,m^2}$

Now, we have to calculate the ammonia which is entering with the feed gas. So, the ammonia entering with the feed gas, which is equal to 34.63 into 0.01; this is this much kilo mole per hour meter square which is equal to 0.3463 k mole per hour meter square. Now, of these 99 percent has to be absorbed, so 99 percent of ammonia should be absorbed. Therefore, the ammonia absorbed would be equal to 34.63 into 0.01 into 0.99 kilo mole per hour meter square, so which is equal to 0.3428 k mole per hour meter square.

Now, the ammonia leaving the tower ammonia leaving the tower would be equal to the entering minus absorbed would be the amount living, so it is entering is 0.3463 minus absorbed is 0.3428 kilo mole per hour meter square, and which would be equal to 0.0035 kilo mole per hour meter square.

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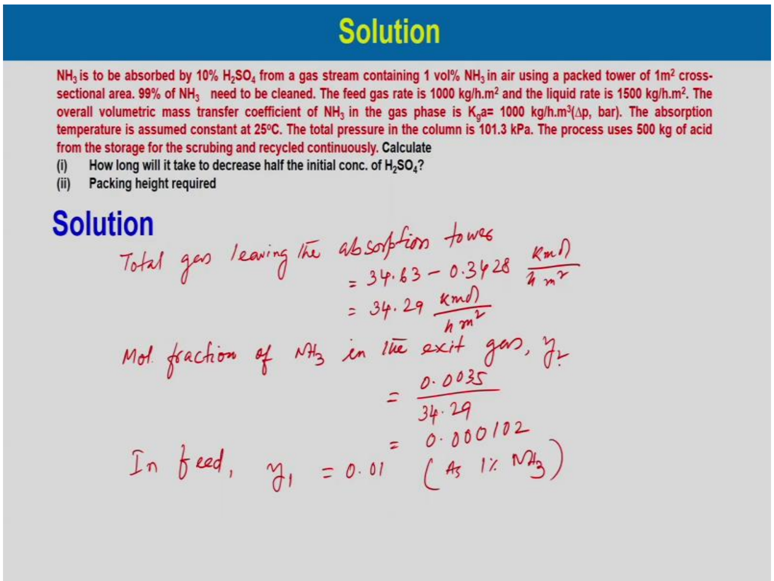

Solution

NH_3 is to be absorbed by 10% H_2SO_4 from a gas stream containing 1 vol% NH_3 in air using a packed tower of 1m^2 cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 1000 kg/h.m^2 and the liquid rate is 1500 kg/h.m^2. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is $K_g a$= 1000 kg/h.m^3(Δp, bar). The absorption temperature is assumed constant at 25°C. The total pressure in the column is 101.3 kPa. The process uses 500 kg of acid from the storage for the scrubing and recycled continuously. Calculate

(i) How long will it take to decrease half the initial conc. of H_2SO_4?
(ii) Packing height required

Solution

Total gas leaving the absorption tower

$$= 34.63 - 0.3428 \ \frac{kmol}{h\ m^2}$$

$$= 34.29 \ \frac{kmol}{h\ m^2}$$

Mol fraction of NH_3 in the exit gas, y_2

$$= \frac{0.0035}{34.29}$$

$$= 0.000102$$

In feed, $y_1 = 0.01$ (As 1% NH_3)

So, the total gas leaving the absorption tower, total gas leaving the absorption tower would be equal to 34.63 minus 0.3428 kilo mole per hour meter square which would be equal to 34.29 kilo mole per hour meter square. So, mole fractions of the ammonia in the exit gas, we can calculate the mole fraction of ammonia which is in the exit gas that is y 2 which is equal to 0.0035 divided by gas which is leaving is 34.29 this much which is equal to 0.000102. And in feed gas in feed, so mole fractions of ammonia y 1 is equal to 0.01 as 1 percent ammonia, so we know y 2 and y 1.

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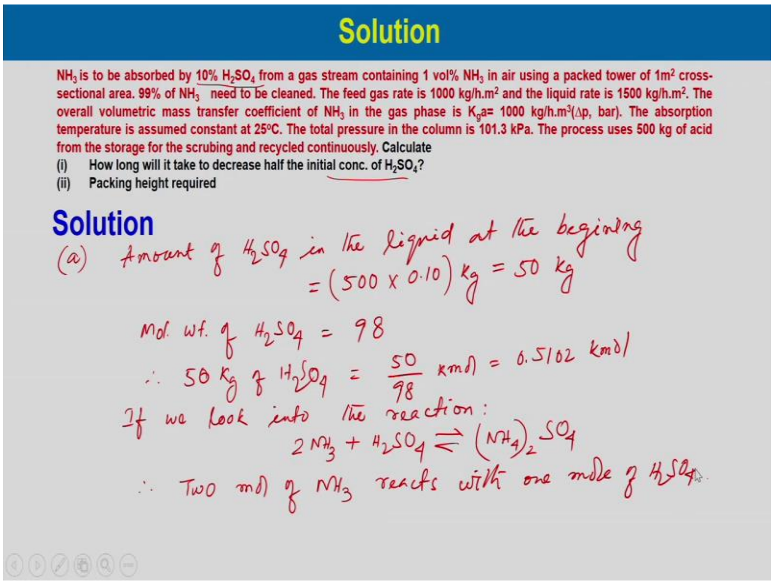

Solution

NH_3 is to be absorbed by 10% H_2SO_4 from a gas stream containing 1 vol% NH_3 in air using a packed tower of 1m^2 cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 1000 kg/h.m^2 and the liquid rate is 1500 kg/h.m^2. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is $K_g a$= 1000 kg/h.m^3(Δp, bar). The absorption temperature is assumed constant at 25°C. The total pressure in the column is 101.3 kPa. The process uses 500 kg of acid from the storage for the scrubing and recycled continuously. Calculate

(i) How long will it take to decrease half the initial conc. of H_2SO_4?

(ii) Packing height required

Solution

(a) Amount of H_2SO_4 in the liquid at the begining

$= (500 \times 0.10)\ kg = 50\ kg$

Mol. wt. of $H_2SO_4 = 98$

$\therefore$ 50 kg of $H_2SO_4 = \frac{50}{98}$ kmol = 0.5102 kmol

If we look into the reaction:

$$2NH_3 + H_2SO_4 \rightleftharpoons (NH_4)_2SO_4$$

$\therefore$ Two mol of NH_3 reacts with one mole of H_2SO_4.

Now, we will solve the first part, how long will it take to decrease half the initial concentration of sulphuric acid. So, part a, we will now solve amount of H 2 S O 4 in the liquid at the beginning, which is equal to 500 kg of acid into 10 percent of know sulphuric acid. So, 10 percent of 5 kg is 0.10 kg, so which is equal to 50 kg.

Now, molecular weight of H 2 SO 4 is 98, so therefore 50 kg of H 2 SO 4 is equal to 50 by 98 kilo mole which is equal to 0.5102 kilo mole. Now, if we look into the reaction, the reactions between ammonia and H 2 SO 4 are sulphuric acid. It is 2 mole of ammonia react with 1 mole of sulphuric acid, and it forms ammonium sulphate NH 4 2 SO 4. Therefore, you can see two mole of ammonia reacts with one mole of sulphuric acid. So, from this we can calculate the acid consumed per hour.

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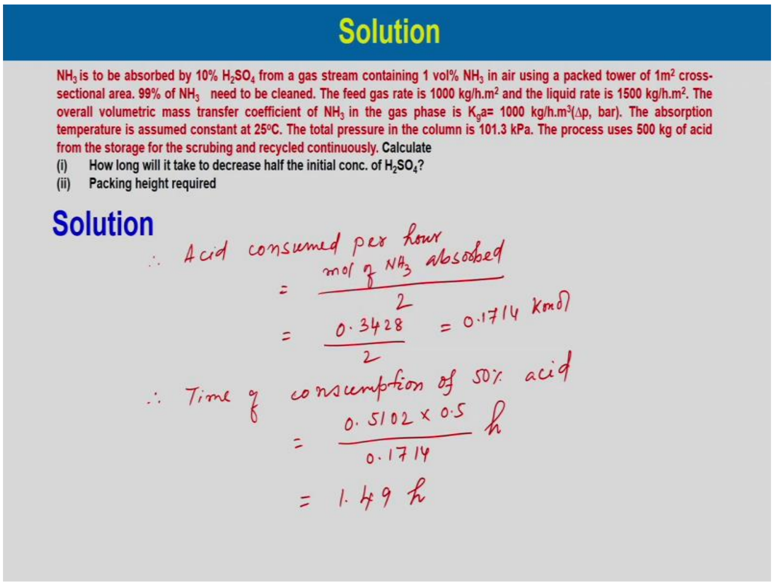

Solution

NH_3 is to be absorbed by 10% H_2SO_4 from a gas stream containing 1 vol% NH_3 in air using a packed tower of $1 m^2$ cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 1000 kg/h.m^2 and the liquid rate is 1500 kg/h.m^2. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is $K_g a$= 1000 kg/h.m^3(Δp, bar). The absorption temperature is assumed constant at 25°C. The total pressure in the column is 101.3 kPa. The process uses 500 kg of acid from the storage for the scrubing and recycled continuously. Calculate

(i) How long will it take to decrease half the initial conc. of H_2SO_4?

(ii) Packing height required

Solution

∴ Acid consumed per hour

$$= \frac{\text{mol of } NH_3 \text{ absorbed}}{2}$$

$$= \frac{0.3428}{2} = 0.1714 \text{ kmol}$$

∴ Time of consumption of 50% acid

$$= \frac{0.5102 \times 0.5}{0.1714} h$$

$$= 1.49 h$$

Therefore, acid consumed per hour would be equal to mole of ammonia absorbed divided by 2. So, this would be equal to know 0.3428 divided by 2, which is equal to 0.1714 kilo mole. Therefore, time of consumption of 50 percent acid would be equal to 0.5102 into its 0.5 divided by 0.1714 hour, so which is equal to 1.49 hour. So, this is the time of consumption for know 50 percent acid for the absorption of ammonia.

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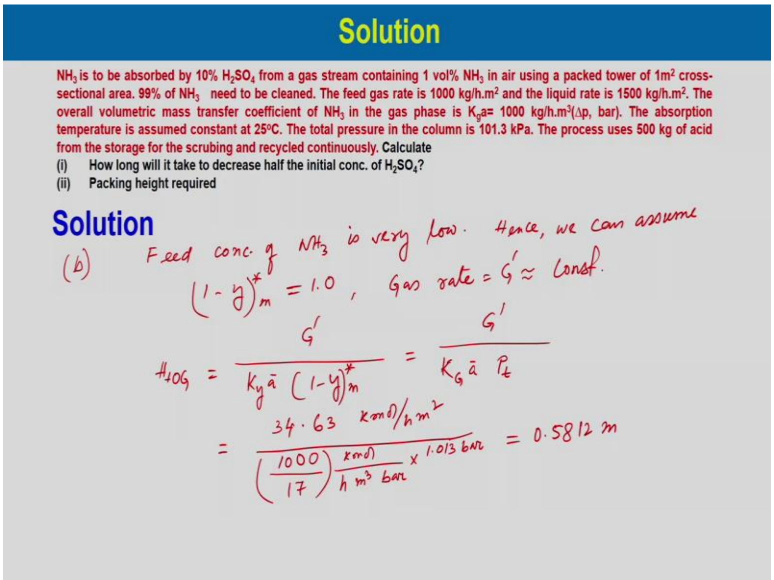

Solution

NH_3 is to be absorbed by 10% H_2SO_4 from a gas stream containing 1 vol% NH_3 in air using a packed tower of $1 m^2$ cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 1000 kg/h.m^2 and the liquid rate is 1500 kg/h.m^2. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is $K_g a$= 1000 kg/h.m^3(Δp, bar). The absorption temperature is assumed constant at 25°C. The total pressure in the column is 101.3 kPa. The process uses 500 kg of acid from the storage for the scrubing and recycled continuously. Calculate

(i) How long will it take to decrease half the initial conc. of H_2SO_4?

(ii) Packing height required

Solution

(b) Feed conc. of NH_3 is very low. Hence, we can assume

$$(1-y)^*_m = 1.0, \quad \text{Gas rate} = G' \approx \text{Const.}$$

$$H_{tOG} = \frac{G'}{K_y \bar{a} (1-y)^*_m} = \frac{G'}{K_G \bar{a} P_t}$$

$$= \frac{34.63 \text{ kmol/h m}^2}{\left(\frac{1000}{17}\right) \frac{\text{kmol}}{\text{h m}^3 \text{ bar}} \times 1.013 \text{ bar}} = 0.5812 m$$

Now, we will move to solve the second part the packing height required. So, part b the height of the packing required. So, feed concentration of the ammonia is very low. So, feed concentration of ammonia is very low, and hence we can assume 1 minus y star m would be equal to 1. And gas rate say G dash it remains approximately constant.

So, H tOG we have to calculate, H tOG would be equal to G dash divided by capital K y a bar into 1 minus y is star m, which would be equal to G dash by K G a bar P t. Now, if you substitute the values, it is 34.63 k mole per hour meter square divided by 1000 by 17 k mole per hour meter cube bar, now if you multiplied with 1.013 bar, so then it would be equal to 0.5812 meter. So, overall height of transfer unit is 0.5 feet 12 meter.

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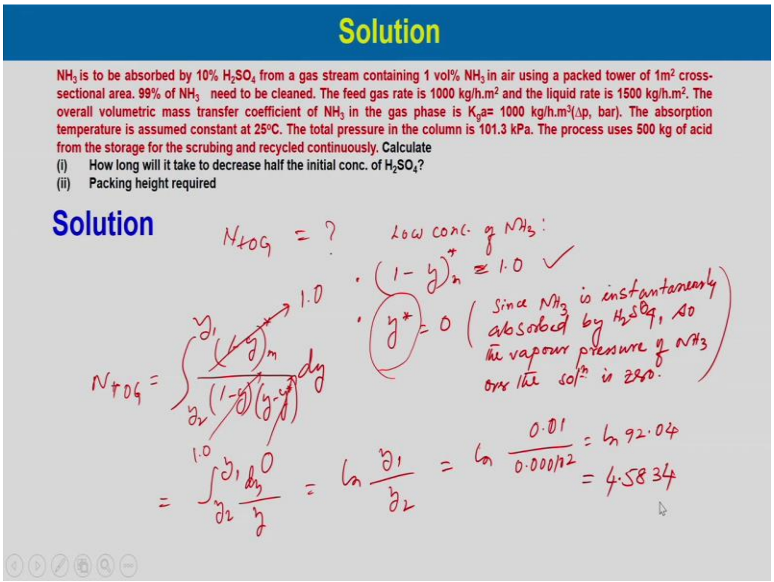

Solution

NH_3 is to be absorbed by 10% H_2SO_4 from a gas stream containing 1 vol% NH_3 in air using a packed tower of 1m^2 cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 1000 kg/h.m^2 and the liquid rate is 1500 kg/h.m^2. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is K_ga= 1000 kg/h.m^3(Δp, bar). The absorption temperature is assumed constant at 25°C. The total pressure in the column is 101.3 kPa. The process uses 500 kg of acid from the storage for the scrubing and recycled continuously. Calculate

(i) How long will it take to decrease half the initial conc. of H_2SO_4?
(ii) Packing height required

Solution

$N_{tOG} = ?$

Low conc. of NH_3:

- $(1-y)^*_m \cong 1.0$ ✓
- $\boxed{y^*} = 0$ (Since NH_3 is instantaneously absorbed by H_2SO_4, so the vapour pressure of NH_3 over the soln is zero.)

$$N_{tOG} = \int_{y_2}^{y_1} \frac{\cancel{(1-y)^*_m}^{\,1.0}}{\cancel{(1-y)}_{1.0}\,(y-\cancel{y^*}_{0})} dy$$

$$= \int_{y_2}^{y_1} \frac{dy}{y} = \ln\frac{y_1}{y_2} = \ln\frac{0.01}{0.000112} = \ln 92.04$$

$$= 4.5834$$

Now, we have to calculate N tOG. Now, since know low concentration of ammonia low concentration of ammonia, we can write 1 minus y star m is equal approximately equal to 1.0. And second thing is that y star would be 0, please note that since ammonia is instantaneously absorbed by H 2 SO 4. So, the vapour pressure of ammonia over the solution is 0.

So, since the ammonia is instantaneously absorbed by sulphuric acid. So, the vapour pressure of ammonia over the solution is zero, since vapour pressure is 0. So, you have equilibrium concentration in the gas phase would be essentially 0. So, this is very important over here for finding the N tOG

As we know the N tOG is equal to integral y 2 to y 1 1 minus y star m divided by 1 minus y into y minus y star dy. In this case, so this is essentially 1.0 as per this and this is essentially equal to also this is equal to 1, this is equal to 0. And hence we have this is equal to integral y 2 to y 1 dy by y, so we can write is equal to ln y 1 by y 2. And now if you substitute ln y 1 is 0.01 divided by 0.000102, which would be equal to ln 92.04, and it will give 4.5834.

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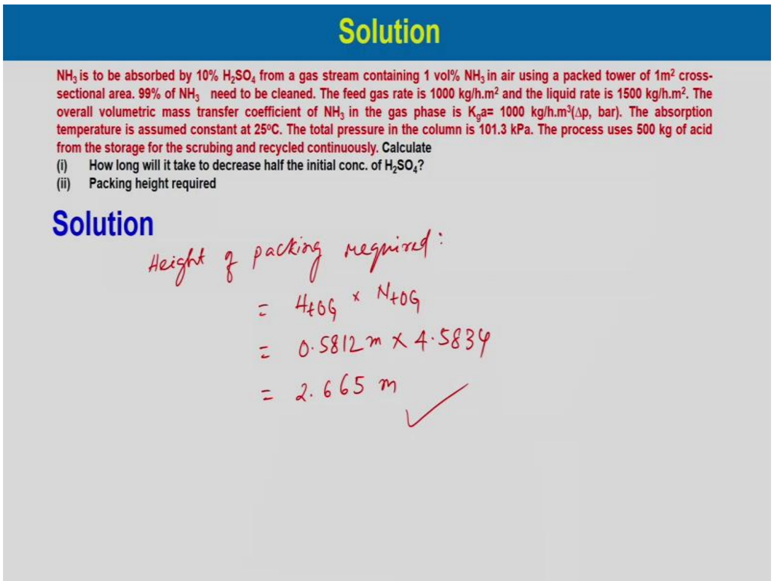

Solution

NH_3 is to be absorbed by 10% H_2SO_4 from a gas stream containing 1 vol% NH_3 in air using a packed tower of $1m^2$ cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 1000 $kg/h.m^2$ and the liquid rate is 1500 $kg/h.m^2$. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is K_ga= 1000 $kg/h.m^3(\Delta p, bar)$. The absorption temperature is assumed constant at 25°C. The total pressure in the column is 101.3 kPa. The process uses 500 kg of acid from the storage for the scrubing and recycled continuously. Calculate

(i) How long will it take to decrease half the initial conc. of H_2SO_4?

(ii) Packing height required

Solution

Height of packing required:

$$= H_{tOG} \times N_{tOG}$$
$$= 0.5812\,m \times 4.5834$$
$$= 2.665\ m \ ✓$$

So, now we know the N tOG as well as H tOG. So, we can calculate the height of packing required height of packing required, we can write is equal to H tOG into N tOG. So, if you substitute H tOG is 0.5812 meter into 4.5834 which is equal to 2.665 meter. So, this is the height of packing required to know do this job. So, this is an example of dilute solution how to solve it, but you can proceed with many other examples.

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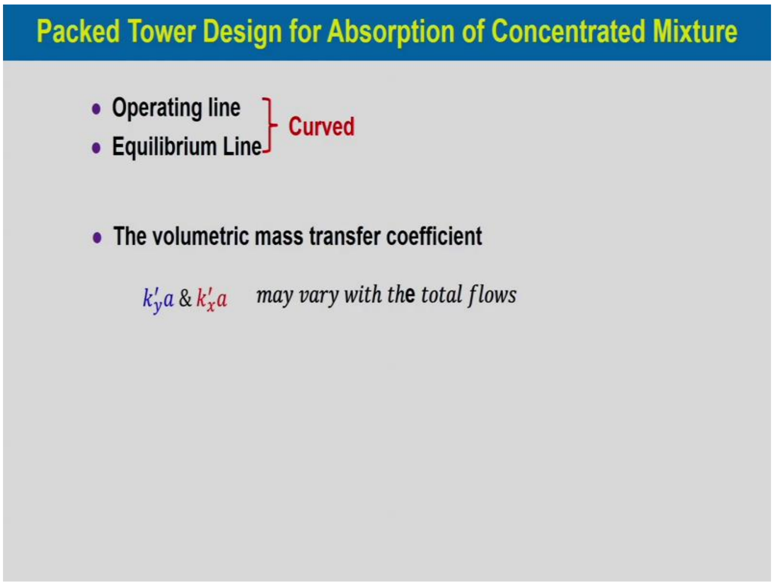

Packed Tower Design for Absorption of Concentrated Mixture

- Operating line
- Equilibrium Line

} Curved

- The volumetric mass transfer coefficient

$k'_y a$ & $k'_x a$ *may vary with the total flows*

Now, if we consider packed tower design for absorption of concentrated mixture, which we have already discussed the fundamentals of it that operating line, and the equilibrium line, they would be the curved line. Now, the volumetric mass transfer coefficient K y dash a and K x dash a may vary with the total flows.

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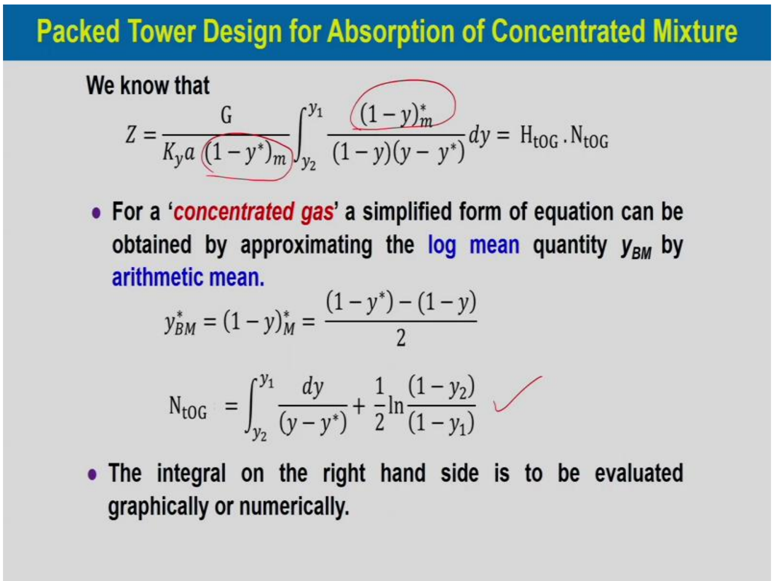

Packed Tower Design for Absorption of Concentrated Mixture

We know that

$$Z = \frac{G}{K_y a\,(1-y^*)_m}\int_{y_2}^{y_1}\frac{(1-y)^*_m}{(1-y)(y-y^*)}\,dy = H_{tOG}\cdot N_{tOG}$$

- For a '*concentrated gas*' a simplified form of equation can be obtained by approximating the log mean quantity y_{BM} by arithmetic mean.

$$y^*_{BM} = (1-y)^*_M = \frac{(1-y^*)-(1-y)}{2}$$

$$N_{tOG} = \int_{y_2}^{y_1}\frac{dy}{(y-y^*)} + \frac{1}{2}\ln\frac{(1-y_2)}{(1-y_1)}$$ ✓

- The integral on the right hand side is to be evaluated graphically or numerically.

So, the design equation must be integrated graphically or numerically, this is already we have discussed. So, the Z H tOG and N tOG, this is the equations we know. And concentrated gas we can simplified form, if we substitute this logarithmic mean with the and if you substitute with the arithmetic mean, so y BM star would be equal to 1 minus y star M would be equal to 1 minus y star minus 1 minus y by 2, this already we have discussed. And finally, we have obtained this relation.

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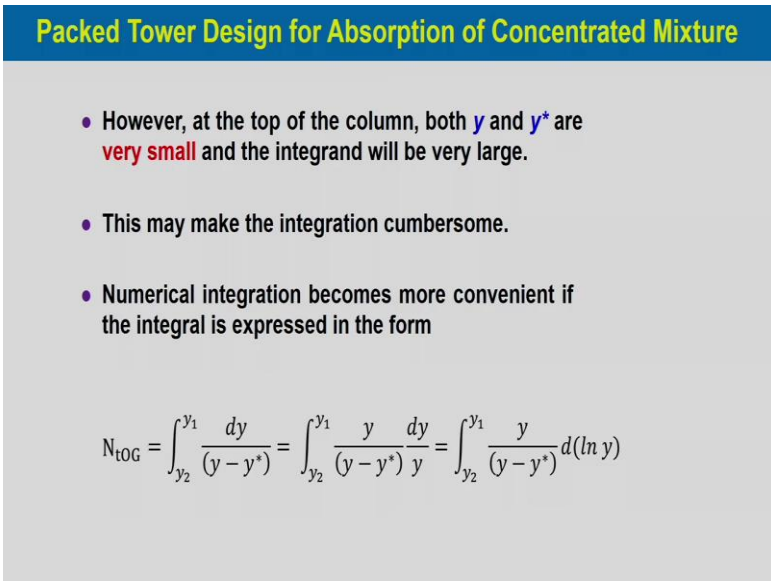

Packed Tower Design for Absorption of Concentrated Mixture

- However, at the top of the column, both *y* and *y** are very small and the integrand will be very large.
- This may make the integration cumbersome.
- Numerical integration becomes more convenient if the integral is expressed in the form

$$N_{tOG} = \int_{y_2}^{y_1} \frac{dy}{(y-y^*)} = \int_{y_2}^{y_1} \frac{y}{(y-y^*)}\frac{dy}{y} = \int_{y_2}^{y_1} \frac{y}{(y-y^*)} d(\ln y)$$

And this is also further simplify, the right hand side can be evaluated, but with a simpler form. Because, at the top of the column both y and y star are very small and the integrand will be very large, so that is why this make integration cumbersome. So, this can be numerical integration becomes more convenient, if the integral is expressed in this form. So, just incorporating over here is integral y 2 to y 1 y y y minus y star d ln y. So, this equation we can simply solve more convenient way than the earlier form.

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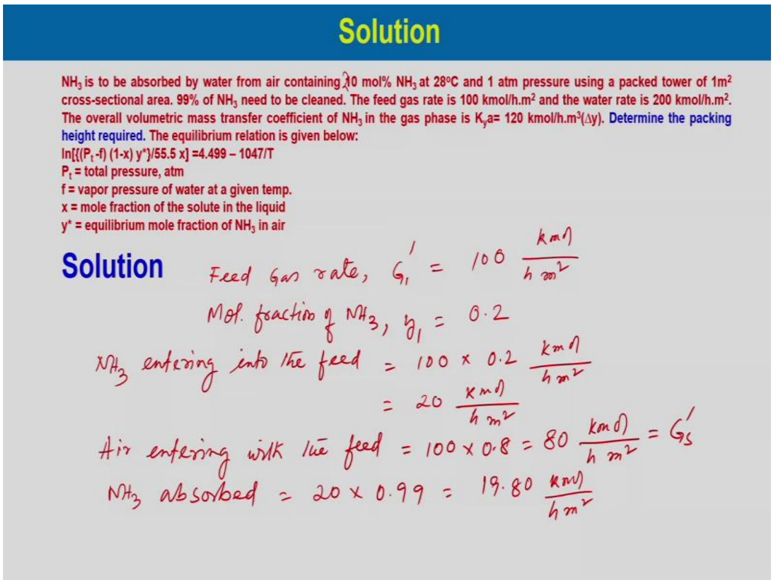

Solution

NH_3 is to be absorbed by water from air containing $\overset{2}{1}0$ mol% NH_3 at 28°C and 1 atm pressure using a packed tower of $1 m^2$ cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 100 $kmol/h.m^2$ and the water rate is 200 $kmol/h.m^2$. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is $K_y a$= 120 $kmol/h.m^3(\Delta y)$. Determine the packing height required. The equilibrium relation is given below:

$\ln[\{(P_t - f)(1-x) y^*\}/55.5 x] = 4.499 - 1047/T$

P_t = total pressure, atm

f = vapor pressure of water at a given temp.

x = mole fraction of the solute in the liquid

y^* = equilibrium mole fraction of NH_3 in air

Solution

Feed Gas rate, $G_1' = 100 \frac{kmol}{h\,m^2}$

Mol. fraction of NH_3, $y_1 = 0.2$

NH_3 entering into the feed $= 100 \times 0.2 \frac{kmol}{h\,m^2}$

$= 20 \frac{kmol}{h\,m^2}$

Air entering with the feed $= 100 \times 0.8 = 80 \frac{kmol}{h\,m^2} = G_s'$

NH_3 absorbed $= 20 \times 0.99 = 19.80 \frac{kmol}{h\,m^2}$

Let us take an example for the concentrated solution. The ammonia is to be absorbed by water from air containing 10 mole percent ammonia at 28 degree centigrade and 1 atmosphere pressure using a packed tower of 1 meter square cross-sectional area. 99 percent of the ammonia need to be cleaned. The feed gas rate is 100 kilo mole per hour meter square. And then the water rate is 200 required per hour meter square. The overall volumetric mass transfer coefficient of ammonia in the gas phase is capital K y a is equal to 120 kilo mole per hour meter square delta y.

Now, we have to determine the packing height required. The equilibrium relation is given, which is over here ln P t minus f in to 1 minus x into y star divided by 55.5 x would be equal 4.499 minus 1047 by T. Now, P t is the total pressure in atmosphere, f is the vapour pressure of water at given temperature, small x is the mole fractions of the solute in the liquid, and y star is the equilibrium mole fraction of ammonia in air.

Now, let us solve this problem for the concentrated solution. So, we have feed gas rate which is we can say G 1 dash is 100 kilo mole per hour meter square. Mole fractions of ammonia that is y 1 is equal to 0.2. So, ammonia entering into the feed would be equal to 100 into 0.2 kilo mole per hour meter square, so it is 20 kilo mole per hour meter square.

Now, the air entering with the feed is equal to 100 into 0.8, which is equal to 80 kilo mole per hour meter square. And this is G s dash. Now, ammonia absorbed know 90 percent, so it is 20 into 0.99, so is about 19.80 k mole per hour meter square. So, this is the amount of ammonia which is absorbed.

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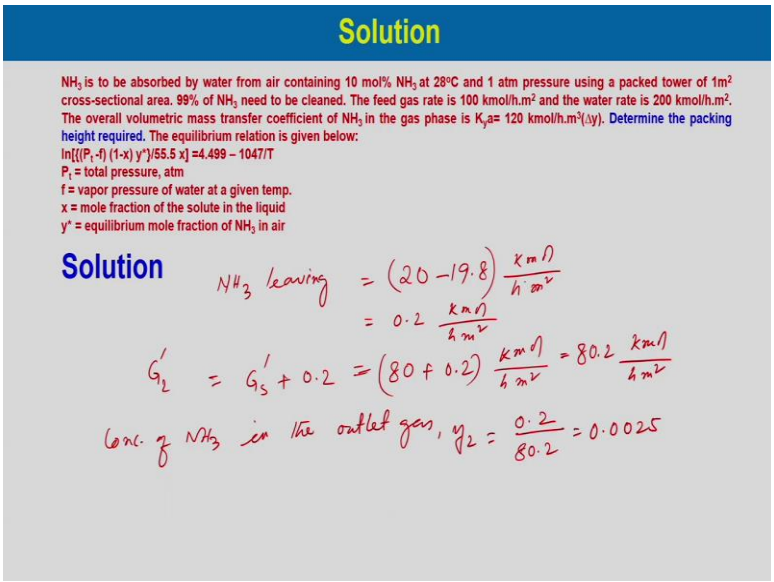

Solution

NH_3 is to be absorbed by water from air containing 10 mol% NH_3 at 28°C and 1 atm pressure using a packed tower of 1m^2 cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 100 kmol/h.m^2 and the water rate is 200 kmol/h.m^2. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is K_ya= 120 kmol/h.m^3(Δy). Determine the packing height required. The equilibrium relation is given below:

ln[{(P_t -f) (1-x) y*}/55.5 x] =4.499 – 1047/T

P_t = total pressure, atm

f = vapor pressure of water at a given temp.

x = mole fraction of the solute in the liquid

y* = equilibrium mole fraction of NH_3 in air

Solution

$$NH_3 \text{ leaving} = (20-19.8)\frac{\text{kmol}}{\text{h m}^2} = 0.2\ \frac{\text{kmol}}{\text{h m}^2}$$

$$G_2' = G_s' + 0.2 = (80 + 0.2)\frac{\text{kmol}}{\text{h m}^2} = 80.2\ \frac{\text{kmol}}{\text{h m}^2}$$

Conc. of NH_3 in the outlet gas, $y_2 = \frac{0.2}{80.2} = 0.0025$

Now, the ammonia leaving ammonia leaving is ammonia 20 kilo mole per hour meter square, and absorb is 19.8 k mole per hour meter square, so it is 0.2 k mole per hour meter square. So, this is the amount of ammonia leaving. So, G 2 dash would be equal to G s dash plus 0.2, so the gas flow rate which is at the leaving conditions would be about 80 plus 0.2 k mole per hour meter square, which is 80.2 k mole per hour meter square. So, the concentration of ammonia in the outlet gas, which is y 2 would be equal to 0.2 divided by 80.2 which is equal to 0.0025.

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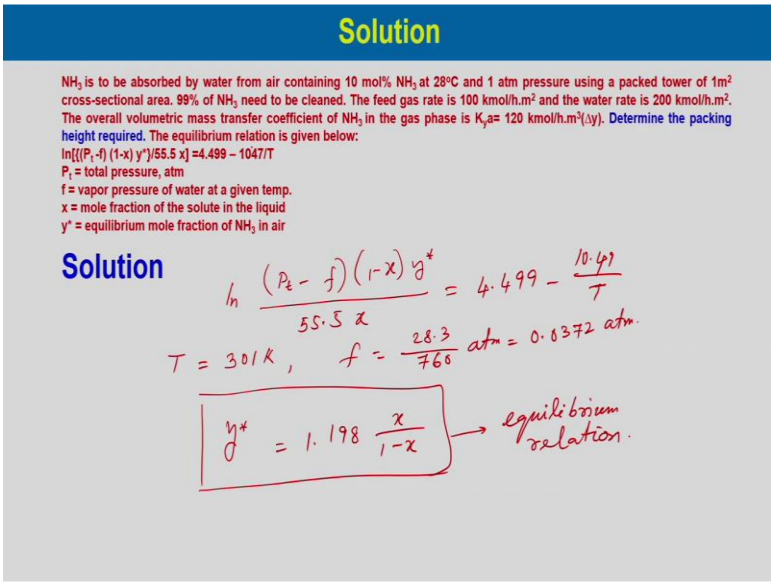

Solution

NH_3 is to be absorbed by water from air containing 10 mol% NH_3 at 28°C and 1 atm pressure using a packed tower of $1m^2$ cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 100 $kmol/h.m^2$ and the water rate is 200 $kmol/h.m^2$. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is K_ya= 120 $kmol/h.m^3(\Delta y)$. Determine the packing height required. The equilibrium relation is given below:

$\ln[\{(P_t - f)(1-x)y^*\}/55.5x] = 4.499 - 1047/T$

P_t = total pressure, atm

f = vapor pressure of water at a given temp.

x = mole fraction of the solute in the liquid

y^* = equilibrium mole fraction of NH_3 in air

Solution

$$\ln \frac{(P_t - f)(1-x)y^*}{55.5x} = 4.499 - \frac{10.49}{T}$$

$$T = 301K, \quad f = \frac{28.3}{760} atm = 0.0372 \ atm.$$

$$\boxed{y^* = 1.198 \frac{x}{1-x}} \rightarrow \text{equilibrium relation.}$$

Now, let us look into the equilibrium relation which is given ln Pt minus f into 1 minus x into y star divided by 55.5 x which is equal to 4.499 minus 10.49 by T. So, this is 10.49. Now, if we substitute T is equal to over here is 301 Kelvin that is 28 degree centigrade f is 28.3 by seventy 760 atmosphere is equal to 0.0372 atmosphere. So, if we substitute over here, we will obtain y star would be equal to 1.198 x by 1 minus x. So, this is the equilibrium relations of x and y.

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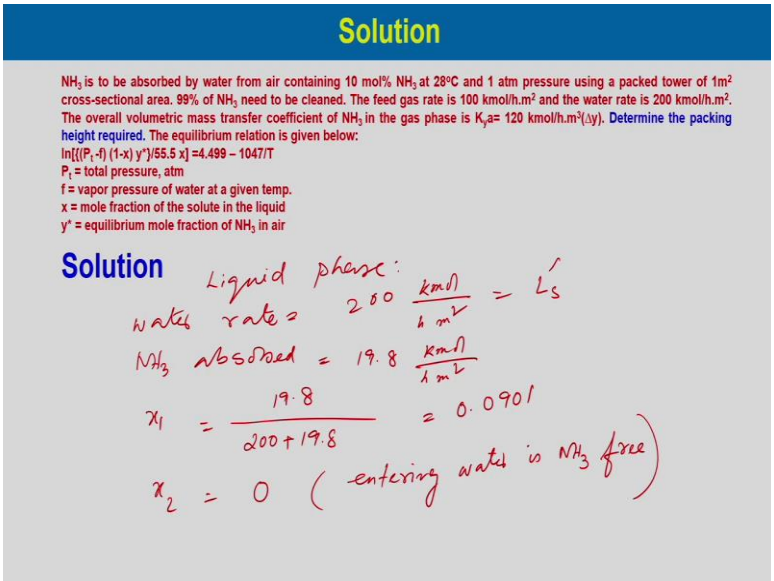

Solution

NH_3 is to be absorbed by water from air containing 10 mol% NH_3 at 28°C and 1 atm pressure using a packed tower of $1m^2$ cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 100 $kmol/h.m^2$ and the water rate is 200 $kmol/h.m^2$. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is K_ya= 120 $kmol/h.m^3(\Delta y)$. Determine the packing height required. The equilibrium relation is given below:

$\ln[\{(P_t - f)(1-x)y^*\}/55.5x] = 4.499 - 1047/T$

P_t = total pressure, atm

f = vapor pressure of water at a given temp.

x = mole fraction of the solute in the liquid

y^* = equilibrium mole fraction of NH_3 in air

Solution

Liquid phase:

$$\text{water rate} = 200 \frac{kmol}{h\,m^2} = L_s'$$

$$NH_3 \text{ absorbed} = 19.8 \frac{kmol}{h\,m^2}$$

$$x_1 = \frac{19.8}{200 + 19.8} = 0.0901$$

$$x_2 = 0 \quad (\text{entering water is } NH_3 \text{ free})$$

Now, liquid rate for the liquid phase, we can calculate the water rate is given which is

200 k mole per hour meter square, and this is say L S dash ammonia absorbed is 19.8 k mole per hour meter square. So, x 1 we can calculate is 19.8 divided by 200 plus 19.8 which is equal to 0.0901. And x 2 is equal to 0, since entering water is free from ammonia or the solute.

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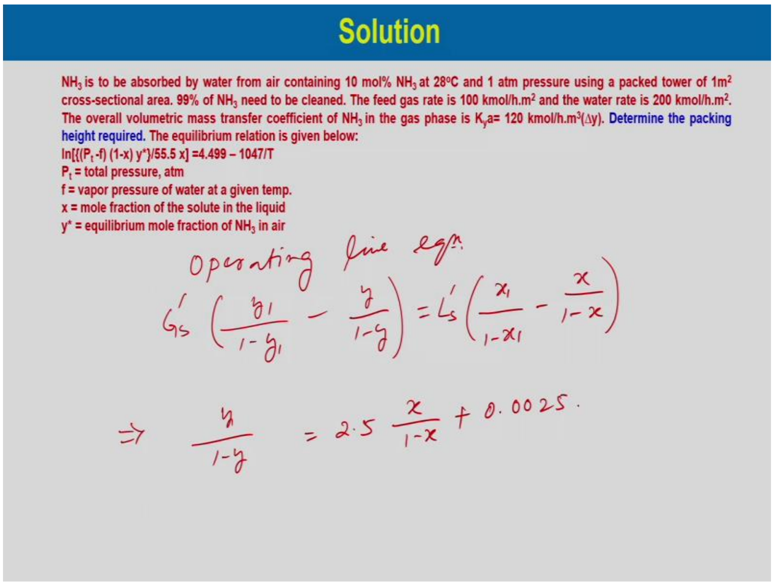

Solution

NH_3 is to be absorbed by water from air containing 10 mol% NH_3 at 28°C and 1 atm pressure using a packed tower of $1 m^2$ cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 100 $kmol/h.m^2$ and the water rate is 200 $kmol/h.m^2$. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is $K_y a = 120\ kmol/h.m^3(\Delta y)$. Determine the packing height required. The equilibrium relation is given below:

$\ln[\{(P_t - f)(1-x)\, y^*\}/55.5\, x] = 4.499 - 1047/T$

P_t = total pressure, atm

f = vapor pressure of water at a given temp.

x = mole fraction of the solute in the liquid

y^* = equilibrium mole fraction of NH_3 in air

Operating line eqn.

$$G_s'\left(\frac{y_1}{1-y_1} - \frac{y}{1-y}\right) = L_s'\left(\frac{x_1}{1-x_1} - \frac{x}{1-x}\right)$$

$$\Rightarrow \frac{y}{1-y} = 2.5\frac{x}{1-x} + 0.0025.$$

So, now if you look into the operating line equation, the operating line equation we know G S dash into y 1 by 1 minus y 1 minus y by 1 minus y would be equal to L S dash x 1 by 1 minus x 1 minus x by 1 minus x. From these if we can just substitute the parameter, we can obtain y by 1 minus y would be equal to 2.5 x by 1 minus x plus 0.0025.

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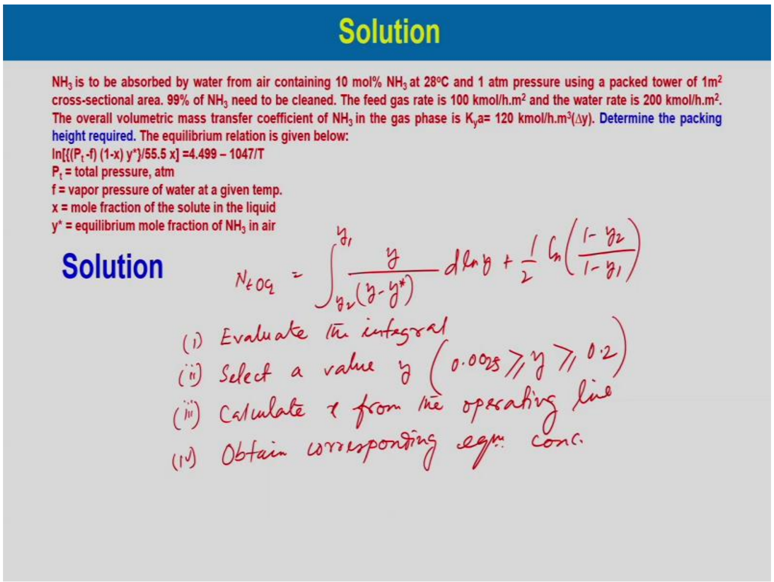

Solution

NH_3 is to be absorbed by water from air containing 10 mol% NH_3 at 28°C and 1 atm pressure using a packed tower of $1 m^2$ cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 100 kmol/h.m^2 and the water rate is 200 kmol/h.m^2. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is $K_y a$= 120 kmol/h.m^3(Δy). Determine the packing height required. The equilibrium relation is given below:

$\ln[\{(P_t - f)(1-x) y^*\}/55.5 x] = 4.499 - 1047/T$

P_t = total pressure, atm

f = vapor pressure of water at a given temp.

x = mole fraction of the solute in the liquid

y^* = equilibrium mole fraction of NH_3 in air

Solution

$$N_{tOG} = \int_{y_2}^{y_1} \frac{y}{(y-y^*)} d\ln y + \frac{1}{2} \ln\left(\frac{1-y_2}{1-y_1}\right)$$

(i) Evaluate the integral

(ii) Select a value y $(0.0025 \geq y \geq 0.2)$

(iii) Calculate x from the operating line

(iv) Obtain corresponding eqm. conc.

Now, we can look into the N tOG equation, Nt og is integral y 2 to y 1 dy divided by y minus y star d ln y plus half ln 1 minus y 2 divided by 1 minus y 1. So, we have to evaluate the integral. Now, to do that, we have to select a value of y, which is in the range of 0.0025 greater than equal to y, and greater than equal to 0.2, because 0.2 is the maximum mole fractions and 0.0025 is the exiting mole fractions. And then calculate x from the operating line, and finally obtain corresponding equilibrium concentration.

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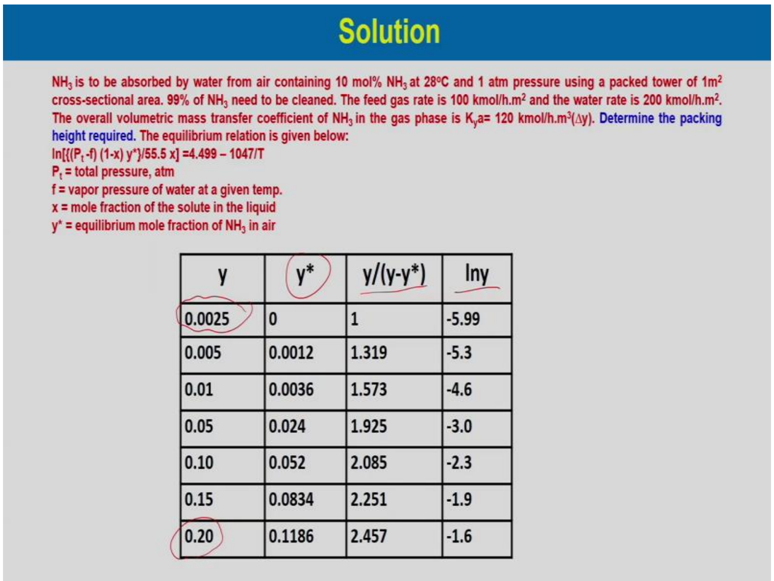

Solution

NH_3 is to be absorbed by water from air containing 10 mol% NH_3 at 28°C and 1 atm pressure using a packed tower of $1 m^2$ cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 100 kmol/h.m^2 and the water rate is 200 kmol/h.m^2. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is $K_y a$= 120 kmol/h.m^3(Δy). Determine the packing height required. The equilibrium relation is given below:

$\ln[\{(P_t - f)(1-x) y^*\}/55.5 x] = 4.499 - 1047/T$

P_t = total pressure, atm

f = vapor pressure of water at a given temp.

x = mole fraction of the solute in the liquid

y^* = equilibrium mole fraction of NH_3 in air

y	y*	y/(y-y*)	lny
0.0025	0	1	-5.99
0.005	0.0012	1.319	-5.3
0.01	0.0036	1.573	-4.6
0.05	0.024	1.925	-3.0
0.10	0.052	2.085	-2.3
0.15	0.0834	2.251	-1.9
0.20	0.1186	2.457	-1.6

So, this is what is done over here, you can see the equilibrium relations, we know we can select a values of y, we can obtain the y star. And once with the range of 0.0025 to 0.2, and we can get y star. And then we can calculate these two terms y by y minus y star, and ln y.

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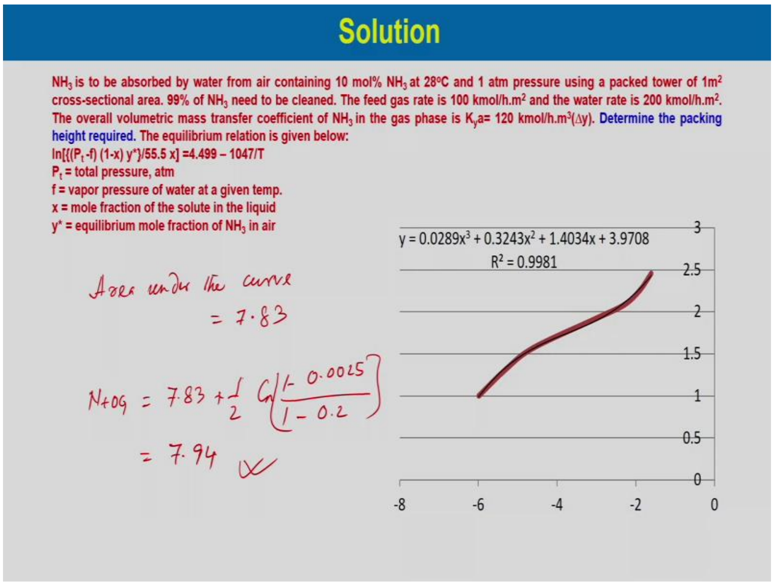

Solution

NH_3 is to be absorbed by water from air containing 10 mol% NH_3 at 28°C and 1 atm pressure using a packed tower of $1 m^2$ cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 100 kmol/h.m^2 and the water rate is 200 kmol/h.m^2. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is K_ya= 120 kmol/h.m^3(Δy). Determine the packing height required. The equilibrium relation is given below:

$\ln[\{(P_t - f)(1-x) y^*\}/55.5 x] = 4.499 - 1047/T$

P_t = total pressure, atm

f = vapor pressure of water at a given temp.

x = mole fraction of the solute in the liquid

y^* = equilibrium mole fraction of NH_3 in air

Area under the curve

$= 7.83$

$$N_{tOG} = 7.83 + \frac{1}{2} \ln\left[\frac{1 - 0.0025}{1 - 0.2}\right]$$

$$= 7.94 \checkmark$$

And finally, if we plot them, we will obtain this graph and then the area under the curve is about 7.83. So, N tOG would be equal to 7.83 plus half ln 1 minus y 2 is 0.0025 divided by 1 minus 0.2. So, this will give about know 7.94 N tOG.

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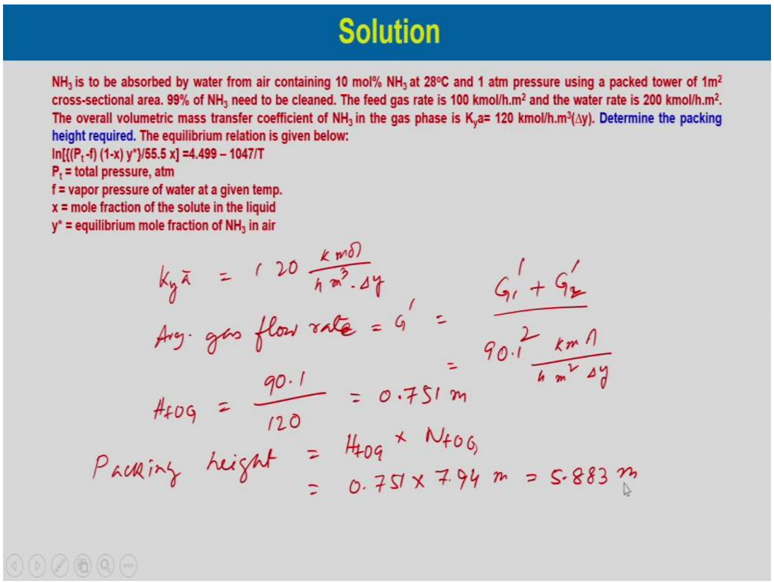

Solution

NH_3 is to be absorbed by water from air containing 10 mol% NH_3 at 28°C and 1 atm pressure using a packed tower of $1 m^2$ cross-sectional area. 99% of NH_3 need to be cleaned. The feed gas rate is 100 kmol/h.m^2 and the water rate is 200 kmol/h.m^2. The overall volumetric mass transfer coefficient of NH_3 in the gas phase is K_ya= 120 kmol/h.m^3(Δy). Determine the packing height required. The equilibrium relation is given below:

$\ln[\{(P_t - f)(1-x) y^*\}/55.5 x] = 4.499 - 1047/T$

P_t = total pressure, atm

f = vapor pressure of water at a given temp.

x = mole fraction of the solute in the liquid

y^* = equilibrium mole fraction of NH_3 in air

$$K_y\bar{a} = 120 \frac{kmol}{h\,m^3 . \Delta y}$$

$$\text{Avg. gas flow rate} = G' = \frac{G_1' + G_2'}{2}$$

$$= 90.1 \frac{kmol}{h\,m^2\,\Delta y}$$

$$H_{tOG} = \frac{90.1}{120} = 0.751\ m$$

$$\text{Packing height} = H_{tOG} \times N_{tOG}$$

$$= 0.751 \times 7.94\ m = 5.883\ m$$

So, once we know this, now we can calculate H tOG. So, K y a bar is given 120 k mole per hour meter cube delta y. And average gas flow rate which is equal to G dash G 1 dash plus G 2 dash divided by 2 which is equal to 90.1 k mole per hour meter square delta y. So, H tOG would be equal to 90.1 divided by 120, which is equal to 0.751 meter. So, now the packing height in this case would be equal to H tOG into N tOG, and if you substitute this 0.751 into 7.94 meter, so which is equal to 5.883 meter. So, this way we can find out the packing height for the concentrated solution.

So, thank you for hearing this lecture, and we will continue our discussion on the absorption in the next class.