

Introduction to Design of Packed Columns

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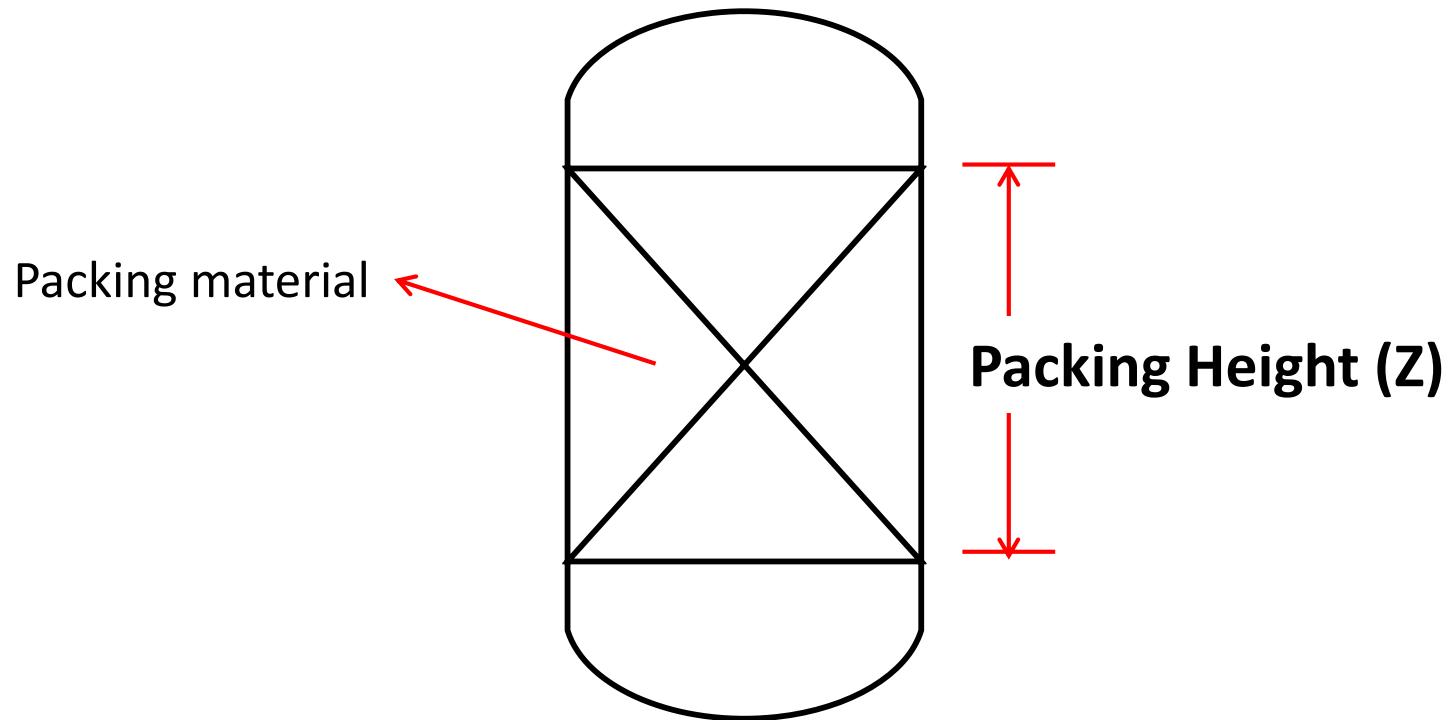
References

1. Wankat: 10.6 – 10.9 and 15.1 – 15.6
2. Coulson & Richardson (Vol 6): 11.14
3. Seader and Henley (Vol 2): Chapter 6

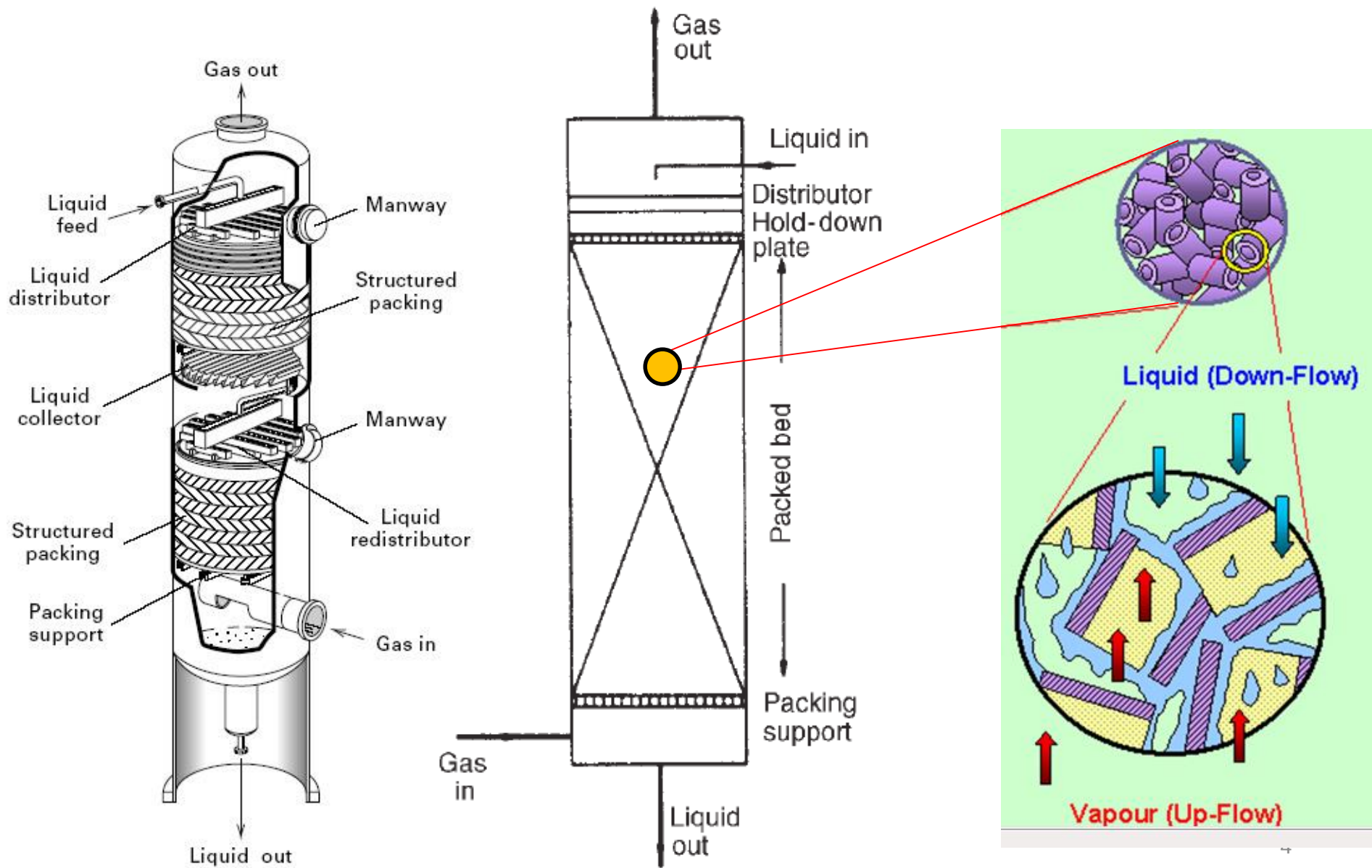
Packed Columns

- Packed columns are used for distillation, gas absorption, and liquid-liquid extraction.
- The gas liquid contact in a packed bed column is continuous, not stage-wise, as in a plate column.
- The liquid flows down the column over the packing surface and the gas or vapor, counter-currently, up the column. Some gas-absorption columns are co-current
- The performance of a packed column is very dependent on the maintenance of good liquid and gas distribution throughout the packed bed.

Representation of a Packed Column



Components of a Packed Column



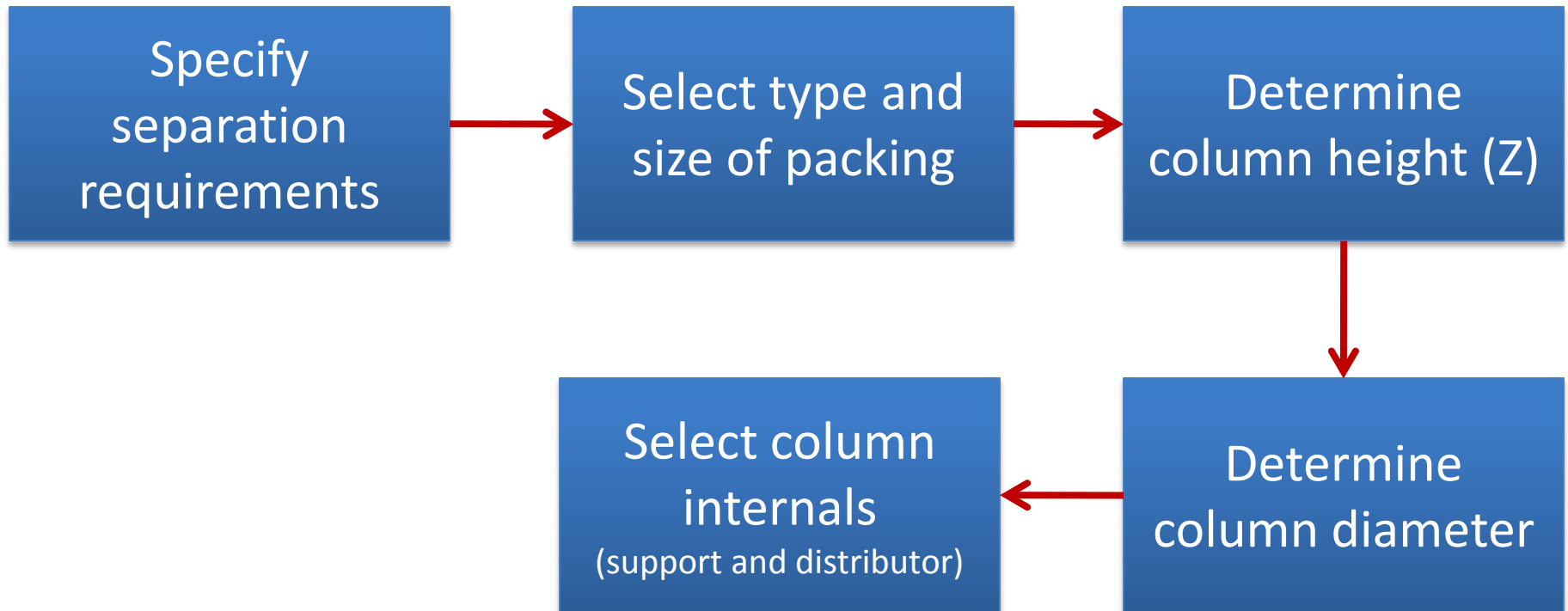
Advantages of Trayed Columns

- 1) Plate columns can handle a wider range of liquid and gas flow-rates than packed columns.
- 2) Packed columns are not suitable for very low liquid rates.
- 3) The efficiency of a plate can be predicted with more certainty than the equivalent term for packing (HETP or HTU).
- 4) Plate columns can be designed with more assurance than packed columns. There is always some doubt that good liquid distribution can be maintained throughout a packed column under all operating conditions, particularly in large columns.
- 5) It is easier to make cooling in a plate column; coils can be installed on the plates.
- 6) It is easier to have withdrawal of side-streams from plate columns.
- 7) If the liquid causes fouling, or contains solids, it is easier to provide cleaning in a plate column; manways can be installed on the plates. With small diameter columns it may be cheaper to use packing and replace the packing when it becomes fouled.

Advantages of Packed Columns

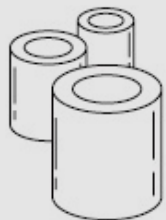
1. For corrosive liquids, a packed column will usually be cheaper than the equivalent plate column.
2. The liquid hold-up is lower in a packed column than a plate column. This can be important when the inventory of toxic or flammable liquids needs to be kept as small as possible for safety reasons.
3. Packed columns are more suitable for handling foaming systems.
4. The pressure drop can be lower for packing than plates; and packing should be considered for vacuum columns.
5. Packing should always be considered for small diameter columns, say less than 0.6 m, where plates would be difficult to install, and expensive.

Design Procedure



Packing Materials

1. **Ceramic:** superior wettability, corrosion resistance at elevated temperature, bad strength
2. **Metal:** superior strength & good wettability
3. **Plastic:** inexpensive, good strength but may have poor wettability at low liquid rate



Ceramic Raschig rings



Ceramic Berl saddle



Ceramic Intalox saddle



Plastic super
Intalox saddle



Metal Intalox IMTP



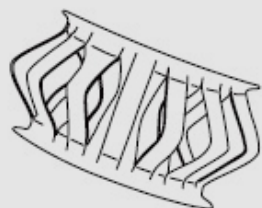
Metal Pall ring



Plastic Flexiring



Metal Bialecki ring



Metal Fleximax



Metal Cascade
Mini-ring (CMR)



Metal Top-pak



Metal Raschig
Super-ring



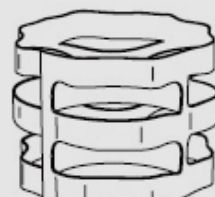
Plastic Tellerette



Plastic Hackett



Plastic Hiflow ring



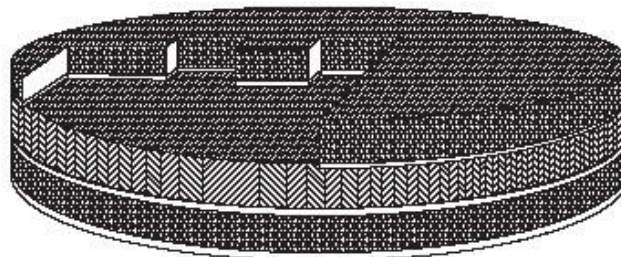
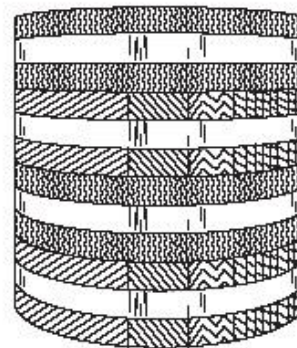
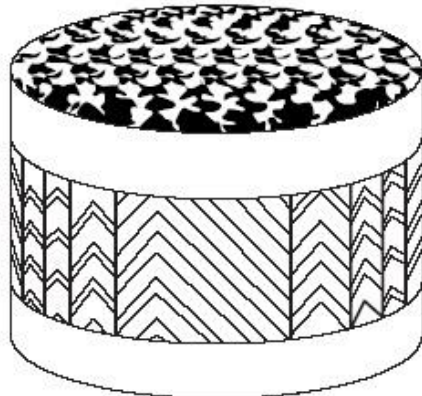
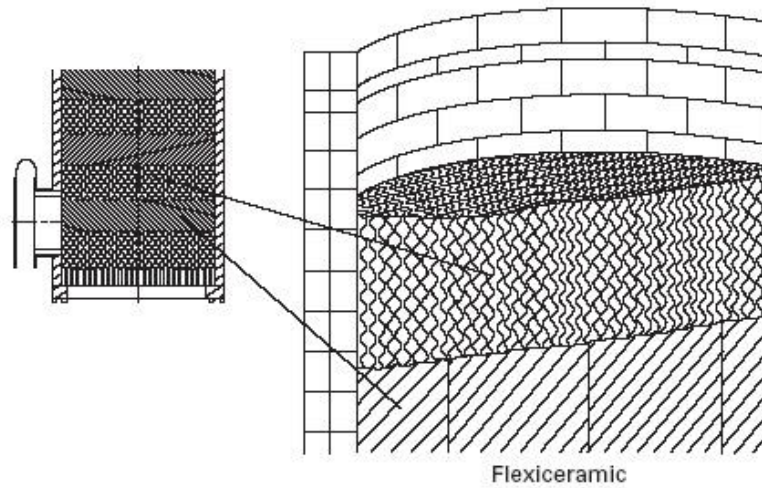
Metal VSP ring

(a)

Reference:
Seader and Henley

Figure 6.7 Typical materials used in a packed column: (a) random packing materials; (*continued*)

Structured packing materials



(b)

Reference:
Seader and Henley

Table 6.8 Characteristics of Packings

Characteristics from Billet											
Packing	Material	Size	F_P , ft ² /ft ³	a , m ² /m ³	ϵ , m ³ /m ³	C_h	C_p	C_L	C_V	C_s	C_{FI}
Random Packings											
Berl saddles	Ceramic	25 mm	110	260.0	0.680	0.620		1.246	0.387		
Berl saddles	Ceramic	13 mm	240	545.0	0.650	0.833		1.364	0.232		
Bialecki rings	Metal	50 mm		121.0	0.966	0.798	0.719	1.721	0.302	2.916	1.896
Bialecki rings	Metal	35 mm		155.0	0.967	0.787	1.011	1.412	0.390	2.753	1.885
Bialecki rings	Metal	25 mm		210.0	0.956	0.692	0.891	1.461	0.331	2.521	1.856
DIN-PAK rings	Plastic	70 mm		110.7	0.938	0.991	0.378	1.527	0.326	2.970	1.912
DIN-PAK rings	Plastic	47 mm		131.2	0.923	1.173	0.514	1.690	0.354	2.929	1.991
Envi Pac rings	Plastic	80 mm, no. 3		60.0	0.955	0.641	0.358	1.603	0.257	2.846	1.522
Envi Pac rings	Plastic	60 mm, no. 2		98.4	0.961	0.794	0.338	1.522	0.296	2.987	1.864
Envi Pac rings	Plastic	32 mm, no. 1		138.9	0.936	1.039	0.549	1.517	0.459	2.944	2.012
Glitsch rings	Metal	30 PMK		180.5	0.975	0.930	0.851	1.920	0.450	2.694	1.900
Glitsch rings	Metal	30 P		164.0	0.959	0.851	1.056	1.577	0.398	2.564	1.760
Glitsch CMR rings	Metal	1.5"		174.9	0.974	0.935	0.632			2.697	1.841
Glitsch CMR rings	Metal	1.5", T		188.0	0.972	0.870	0.627			2.790	1.870
Glitsch CMR rings	Metal	1.0"		232.5	0.971	1.040	0.641			2.703	1.996
Glitsch CMR rings	Metal	0.5"		356.0	0.952		0.882	2.038	0.495	2.644	2.178
Cascade minirings	Metal	30 PMK		180.2	0.975	0.930					
Cascade minirings	Metal	30 P		168.9	0.958	0.851					
Cascade minirings	Metal	1.5" CMR, T		188.0	0.972	0.870					
Cascade minirings	Metal	1.5" CMR	29	174.9	0.974	0.935					
Cascade minirings	Metal	1.0" CMR	40	232.5	0.971	1.040					
Cascade minirings	Metal	0.5" CMR		356.0	0.955	1.338					
Hackettes	Plastic	45 mm		139.5	0.928	0.643	0.399			2.832	1.966
Hiflow rings	Ceramic	75 mm	15	54.1	0.868		0.435				
Hiflow rings	Ceramic	50 mm	29	89.7	0.809		0.538	1.377	0.379	2.819	1.694
Hiflow rings	Ceramic	38 mm	37	111.8	0.788		0.621	1.659	0.464	2.840	1.930
Hiflow rings	Ceramic	20 mm, 6 stg.		265.8	0.776	0.958					
Hiflow rings	Ceramic	20 mm, 4 stg.		261.2	0.779	1.167	0.628	1.744	0.465		
Hiflow rings	Metal	50 mm	16	92.3	0.977	0.876	0.421	1.168	0.408	2.702	1.626
Hiflow rings	Metal	25 mm	42	202.9	0.962	0.799	0.689	1.641	0.402	2.918	2.177
Hiflow rings	Plastic	90 mm	9				0.276				
Hiflow rings	Plastic	50 mm, hydr.					0.311	1.553	0.369	2.894	1.871
Hiflow rings	Plastic	50 mm	20				0.327	1.487	0.345		

Reference:
Seader and Henley

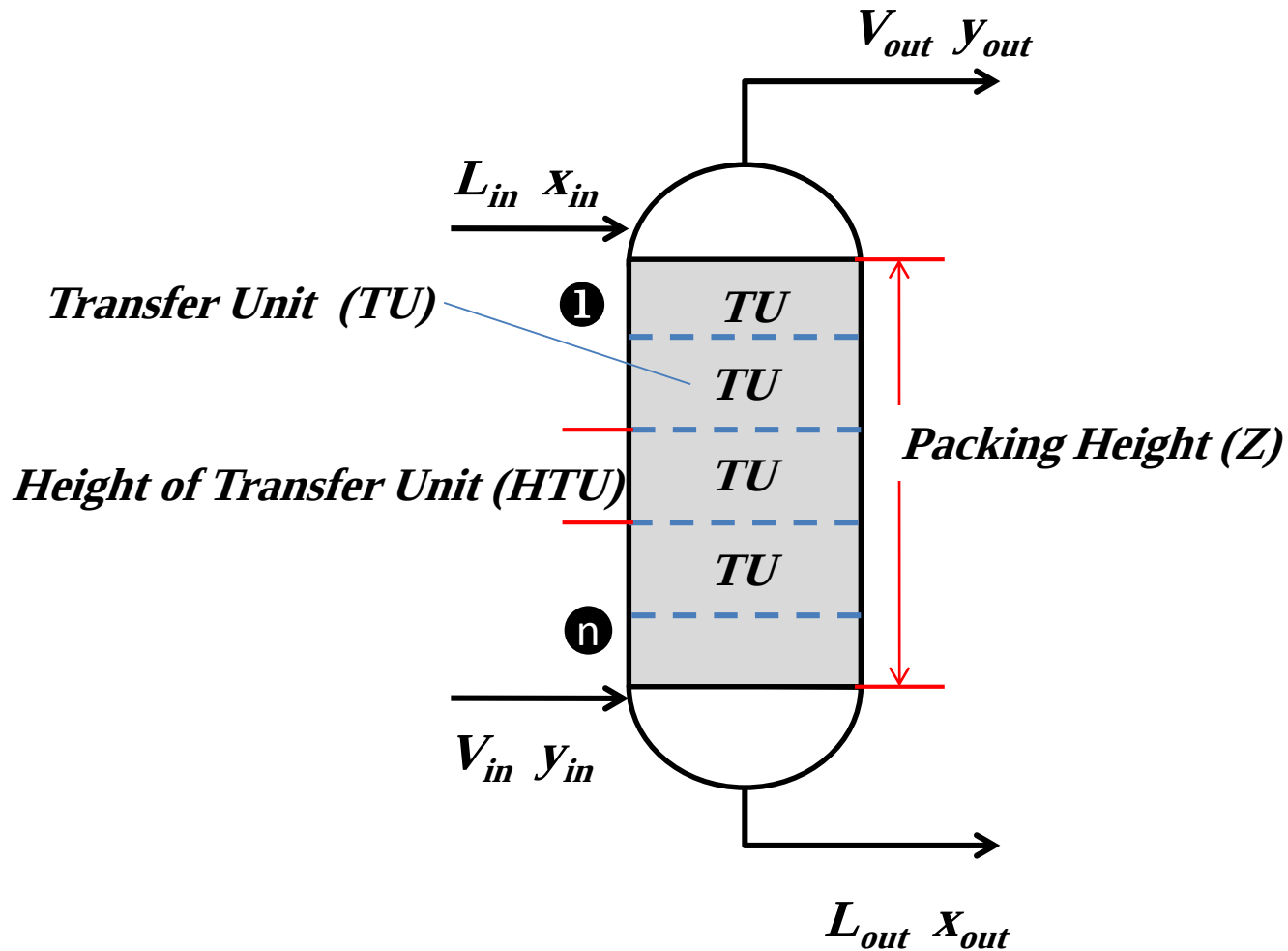
Characteristics of Packing

Table 6.3 Comparison of Types of Packing

	Random		Structured
	Raschig Rings and Saddles	“Through Flow”	
Relative cost	Low	Moderate	High
Pressure drop	Moderate	Low	Very low
Efficiency	Moderate	High	Very high
Vapor capacity	Fairly high	High	High
Typical turndown ratio	2	2	2

Reference:
Seader and Henley

Packing Height (Z)



Packing Height (Z) = height of transfer unit (HTU) × number of transfer units (n)

Methods for Packing Height (Z)

2 methods

Equilibrium stage
analysis
HETP method

Mass Transfer
analysis
HTU method

More common

$$Z = \text{HETP} \times N$$

N = number of theoretical stages obtained from McCabe-Thiele method

HETP

- Height Equivalent to a Theoretical Plate
- Represents the height of packing that gives similar separation to as a theoretical stage.
- HETP values are provided for each type of packing

$$Z = \text{HTU} \times \text{NTU}$$

HTU = Height of a Transfer unit

NTU = Number of Transfer Units (obtained by numerical integration)

$$Z = \frac{V}{K_y a A_c} \int_{y_{Ain}}^{y_{Aout}} \frac{dy}{(y_A^* - y_A)} \quad Z = H_{OG} \times N_{OG}$$

$$Z = \frac{L}{K_x a A_c} \int_{x_{Ain}}^{x_{Aout}} \frac{dx_A}{(x_A - x_A^*)} \quad Z = H_{OL} \times N_{OL}$$

Evaluating height based on HTU-NTU model

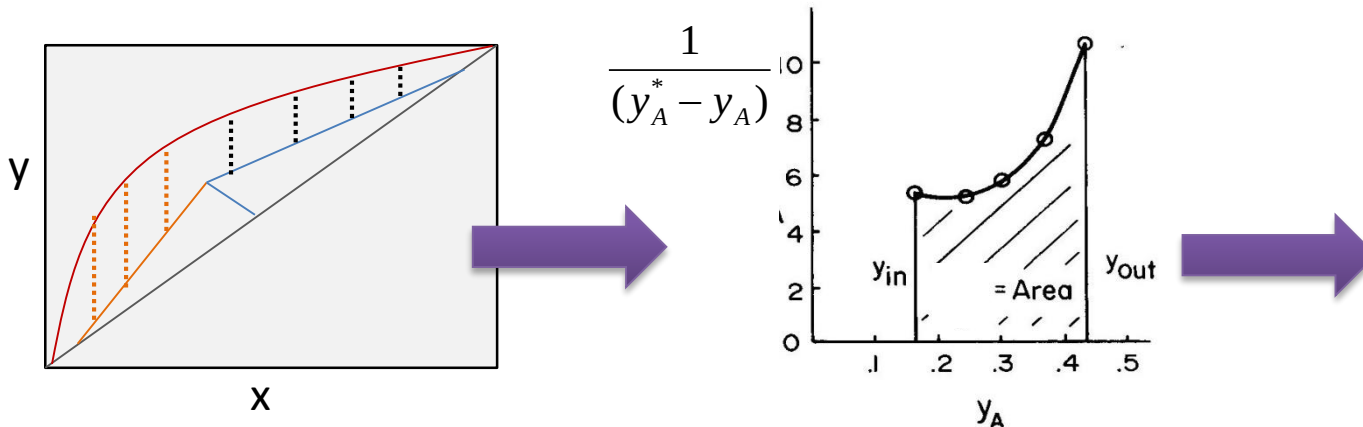
$$Z = \frac{V}{K_y a A_c} \int_{y_{Ain}}^{y_{Aout}} \frac{dy}{(y_A^* - y_A)}$$

H_{OG}

Substitute values to calculate H_{OG}

Integration = N_{OG}

- N_{OG} is evaluated graphically by numerical integration using the equilibrium and operating lines.
- Draw $1/(y_A^* - y_A)$ (on y-axis) vs. y_A (on x-axis). Area under the curve is the value of integration.



Two-Film Theory of Mass Transfer

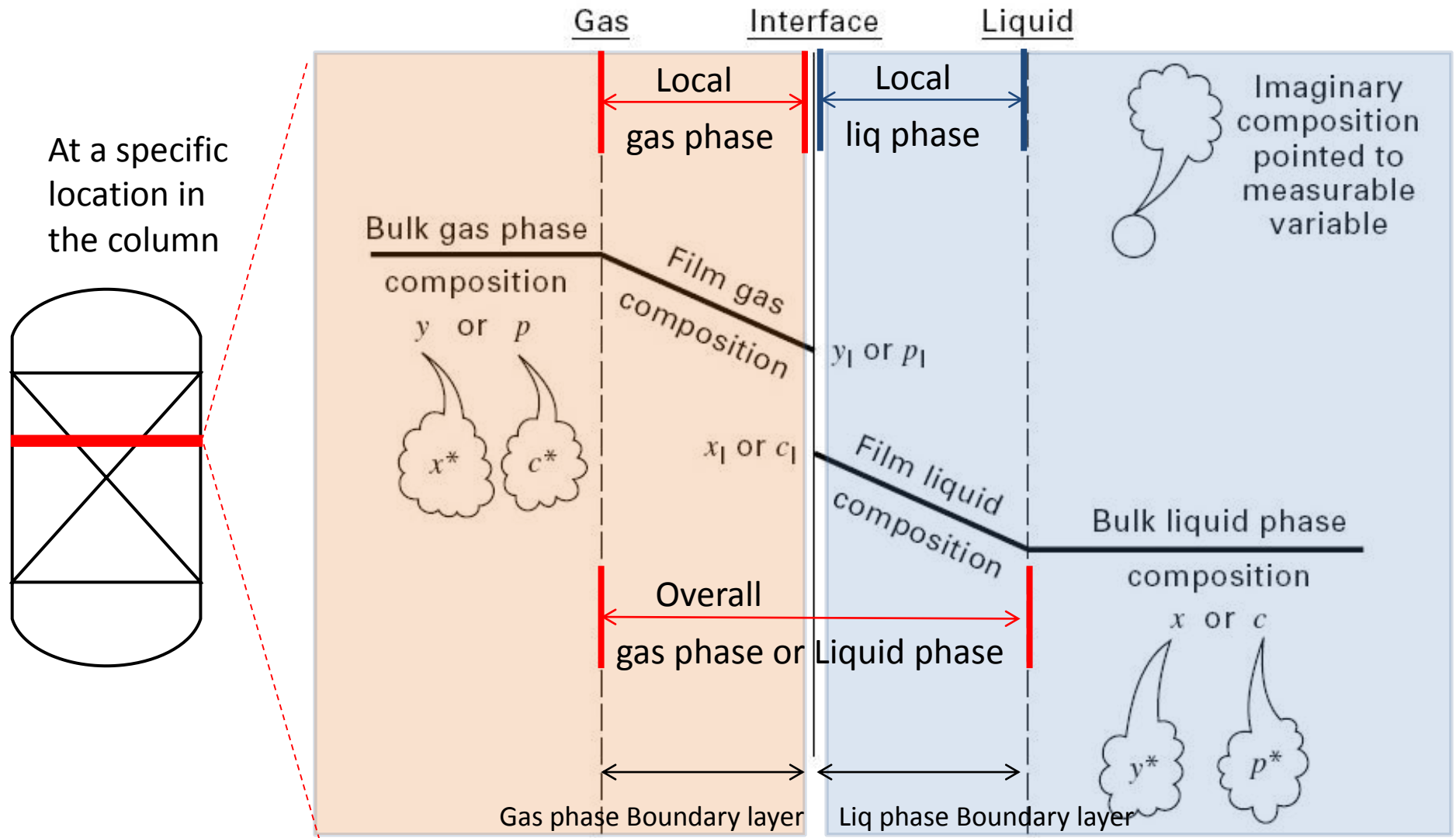


Figure 6.30 Interface properties in terms of bulk properties.

Alternative Mass Transfer Grouping

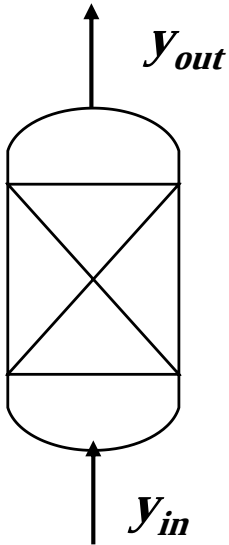
Phase	LOCAL coefficient	OVERALL coefficient
Gas Phase	$Z = H_G \times N_G$ M. Transfer Coeff.: $k_y a$ Driving force: $(y - y_i)$	$Z = H_{OG} \times N_{OG}$ M. Transfer Coeff.: $K_y a$ Driving force: $(y - y^*)$
Liquid Phase	$Z = H_L \times N_L$ M. Transfer Coeff.: $k_x a$ Driving force: $(x - x_i)$	$Z = H_{OL} \times N_{OL}$ M. Transfer Coeff.: $K_x a$ Driving force: $(x - x^*)$

Note: Driving force could be $(y - y_i)$ or $(y_i - y)$ is decided based on direction of flow. This applies to gas and liquid phases, overall and local.

Graphical evaluation of N (integral)

Assume we are evaluating

$$N_{OG} = \int_{y_{Ain}}^{y_{Aout}} \frac{dy_A}{(y_A^* - y_A)} = \int_{y_{Ain}}^{y_{Aout}} \frac{1}{(y_A^* - y_A)} dy_A$$



y_A	y_A^*	$(y_A^* - y_A)$	$1/(y_A^* - y_A)$
y_{Ain}	↓	↓	↓
↓	↓	↓	↓
y_{Aout}	↓	↓	↓

- Use Equilibrium data related to process (e.g., x-y for absorption and stripping) and the operating line (from mass balance).
- Obtain data of the integral in the given range and fill in the table
- Draw y_A vs. $1/(y_A^* - y_A)$
- Then find area under the curve graphically or numerically

Distillation random case

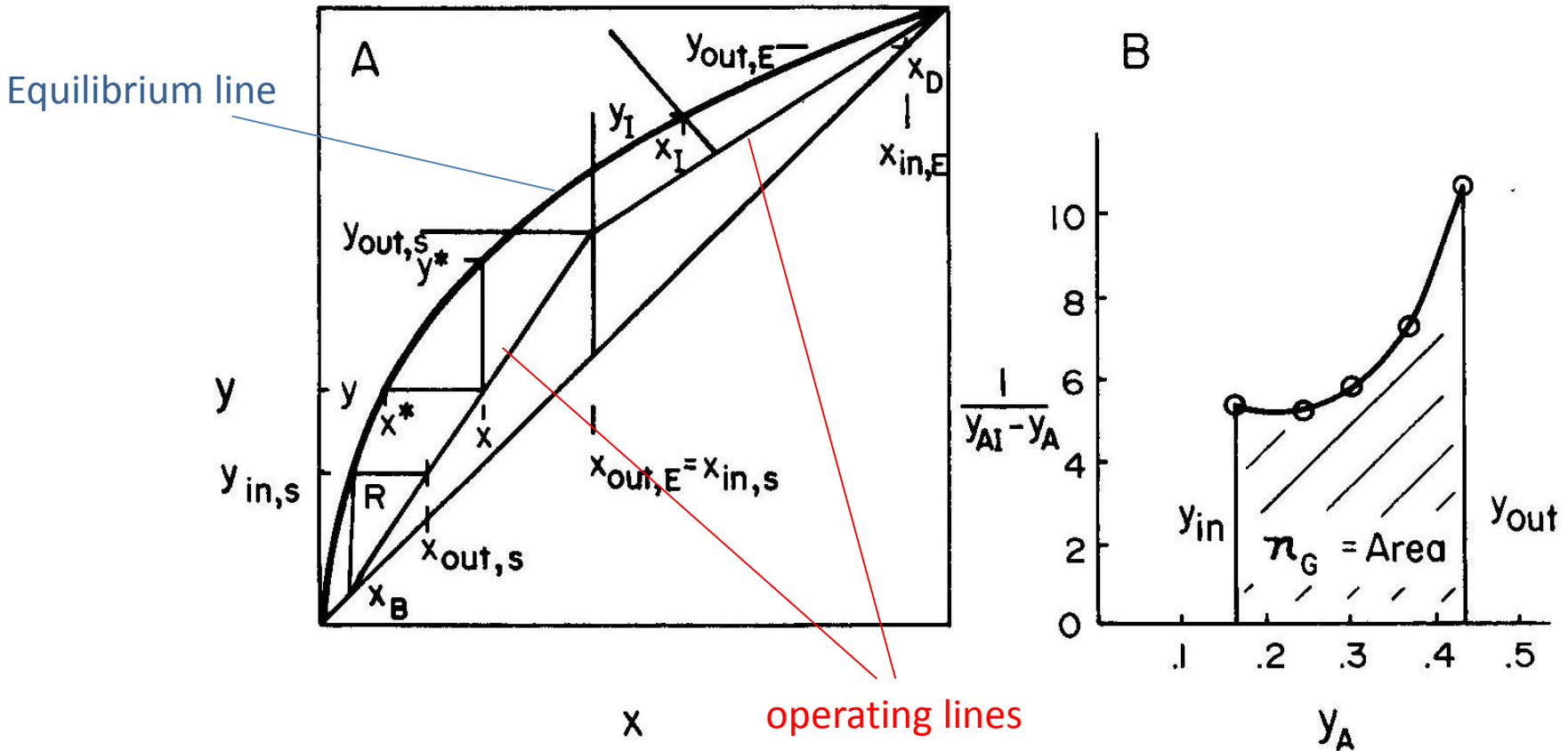


FIGURE 15-3. Analysis of number of transfer units; A) determination of equilibrium or interfacial values, B) graphical integration of Eq. (15-12b) shown for stripping section of Example 15-1

Simpson's Rule for approximating the integral

7 point Simpson's rule:

$$\int_{X_0}^{X_6} f(X) dX = \frac{h}{3} [f(X_0) + 4f(X_1) + 2f(X_2) + 4f(X_3) + 2f(X_4) + 4f(X_5) + f(X_6)]$$
$$h = \frac{(X_6 - X_0)}{6}$$

5 points Simpson's rule:

$$\int_{X_0}^{X_4} f(X) dX = \frac{h}{3} [f(X_0) + 4f(X_1) + 2f(X_2) + 4f(X_3) + f(X_4)]$$

$$h = \frac{(X_4 - X_0)}{4}$$

3 points Simpson's rule:

$$\int_{X_0}^{X_2} f(X) dX = \frac{h}{3} [f(X_0) + 4f(X_1) + f(X_2)]$$

$$h = \frac{(X_2 - X_0)}{2}$$

ABSORPTION/STRIPPING IN PACKED COLUMNS

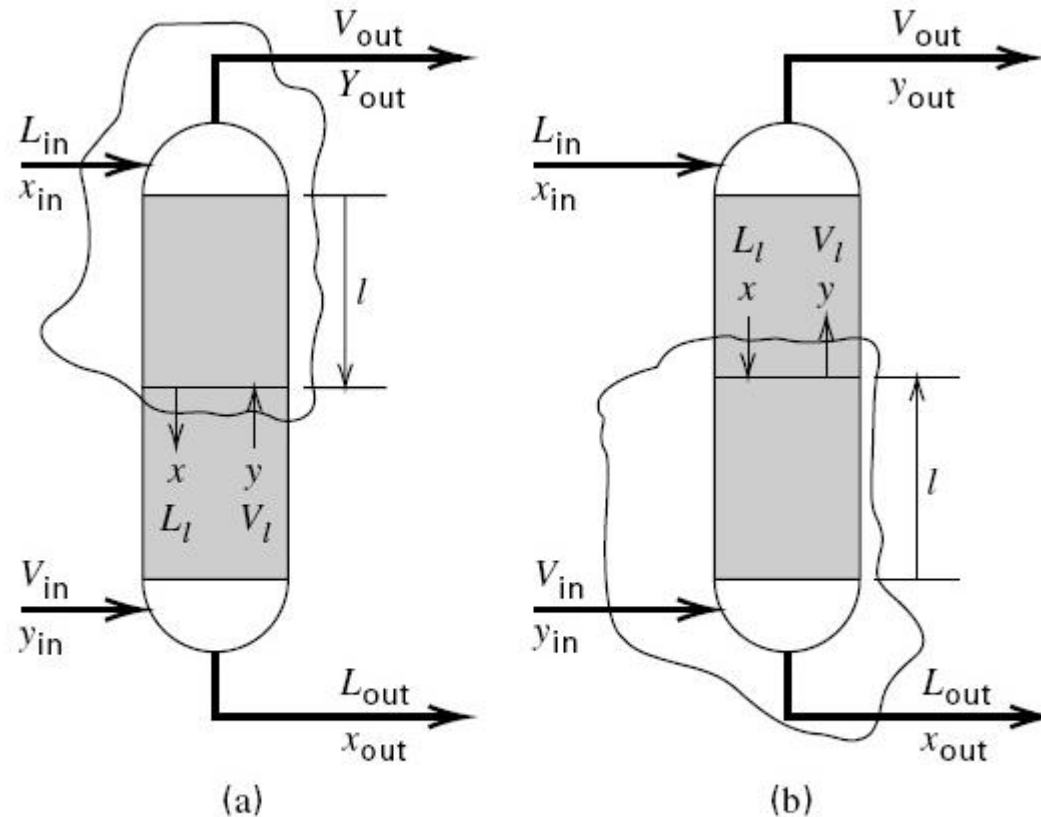


Figure 6.29 Packed columns with countercurrent flow:
 (a) absorber; (b) stripper. Ref.: Seader and Henley

$$Y_{n+1} = \frac{L'}{V'} X_n + (Y_1 - \frac{L'}{V'} X_o)$$

Table 6.7 Alternative Mass-Transfer Coefficient Groupings

Driving Force	Height of a Transfer Unit, HTU			Number of Transfer Units, NTU		
	Symbol	EM Diffusion or Dilute UM Diffusion	UM Diffusion	Symbol	EM Diffusion ^a or Dilute UM Diffusion	UM Diffusion
1. $(y - y^*)$	H_{OG}	$\frac{V}{K_y a S}$	$\frac{V}{K'_y a (1 - y)_{LM} S}$	N_{OG}	$\int \frac{dy}{(y - y^*)}$	$\int \frac{(1 - y)_{LM} dy}{(1 - y)(y - y^*)}$
2. $(p - p^*)$	H_{OG}	$\frac{V}{K_G a P S}$	$\frac{V}{K'_G a (1 - y)_{LM} P S}$	N_{OG}	$\int \frac{dp}{(p - p^*)}$	$\int \frac{(P - p)_{LM} dp}{(P - p)(p - p^*)}$
3. $(Y - Y^*)$	H_{OG}	$\frac{V'}{K_Y a S}$	$\frac{V'}{K'_Y a S}$	N_{OG}	$\int \frac{dY}{(Y - Y^*)}$	$\int \frac{dY}{(Y - Y^*)}$
4. $(y - y_1)$	H_G	$\frac{V}{k_y a S}$	$\frac{V}{k'_y a (1 - y)_{LM} S}$	N_G	$\int \frac{dy}{(y - y_1)}$	$\int \frac{(1 - y)_{LM} dy}{(1 - y)(y - y_1)}$
5. $(p - p_1)$	H_G	$\frac{V}{k_p a P S}$	$\frac{V}{k'_p a (P - p)_{LM} S}$	N_G	$\int \frac{dp}{(p - p_1)}$	$\int \frac{(P - p)_{LM} dp}{(P - p)(p - p_1)}$
6. $(x^* - x)$	H_{OL}	$\frac{L}{K_x a S}$	$\frac{L}{K'_x a (1 - x)_{LM} S}$	N_{OL}	$\int \frac{dx}{(x^* - x)}$	$\int \frac{(1 - x)_{LM} dx}{(1 - x)(x^* - x)}$
7. $(c^* - c)$	H_{OL}	$\frac{L}{K_L a (\rho_L / M_L) S}$	$\frac{L}{K'_L a (\rho_L / M_L - c)_{LM} S}$	N_{OL}	$\int \frac{dc}{(c^* - c)}$	$\int \frac{(\rho_L / M_L - c)_{LM} dx}{(\rho_L / M_L - c)(c^* - c)}$
8. $(X^* - X)$	H_{OL}	$\frac{L'}{K_X a S}$	$\frac{L'}{K'_X a S}$	N_{OL}	$\int \frac{dX}{(X^* - X)}$	$\int \frac{dX}{(X^* - X)}$
9. $(x_1 - x)$	H_L	$\frac{L}{k_x a S}$	$\frac{L}{k'_x a (1 - x)_{LM} S}$	N_L	$\int \frac{dx}{(x_1 - x)}$	$\int \frac{(1 - x)_{LM} dx}{(1 - x)(x_1 - x)}$
10. $(c_1 - c)$	H_L	$\frac{L}{k_L a (\rho_L / M_L) S}$	$\frac{L}{k'_L a (\rho_L / M_L - c)_{LM} S}$	N_L	$\int \frac{dc}{(c_1 - c)}$	$\int \frac{(\rho_L / M_L - c)_{LM} dc}{(\rho_L / M_L - c)(c_1 - c)}$

^aThe substitution $K_y = K'_y y_{B,LM}$ or its equivalent can be made.

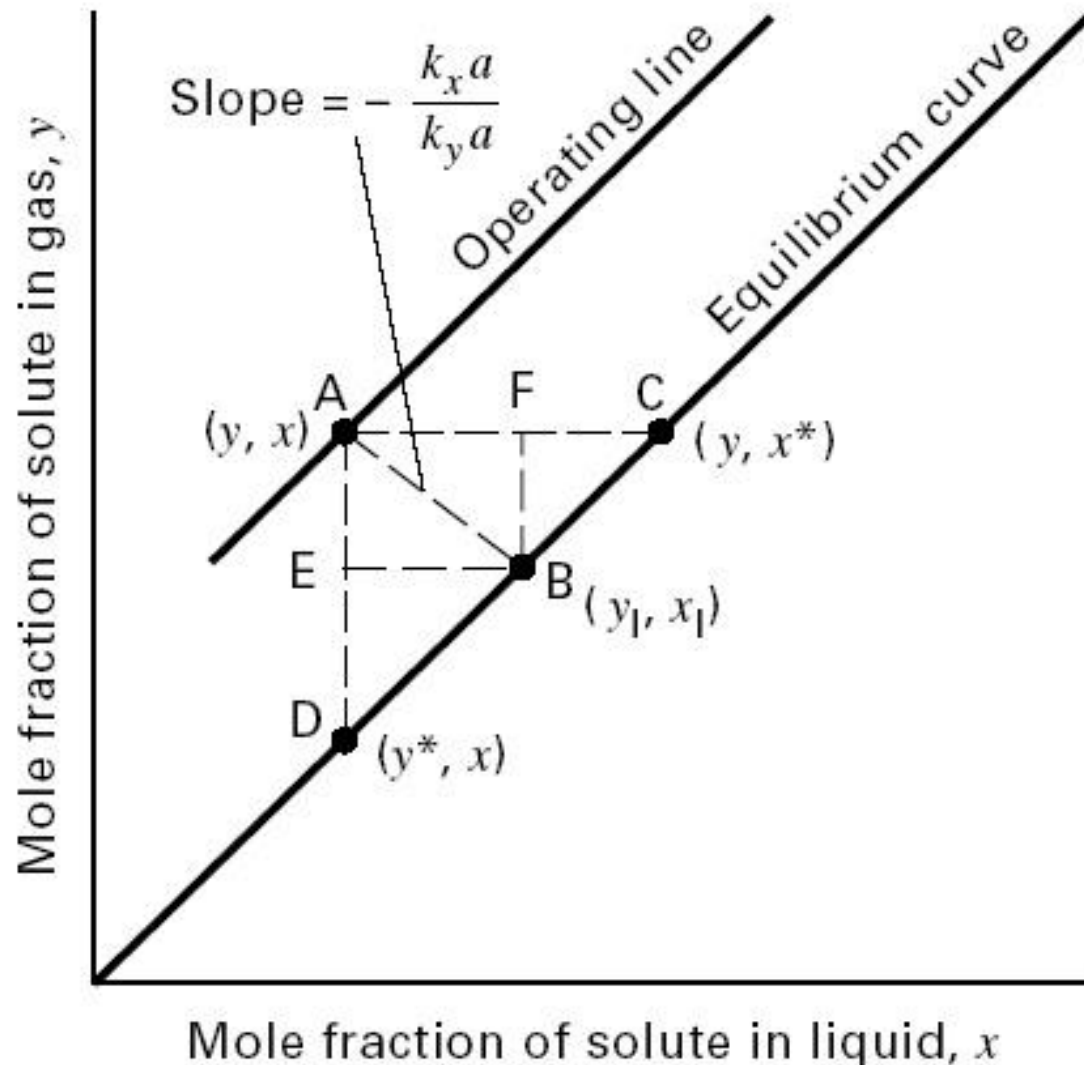
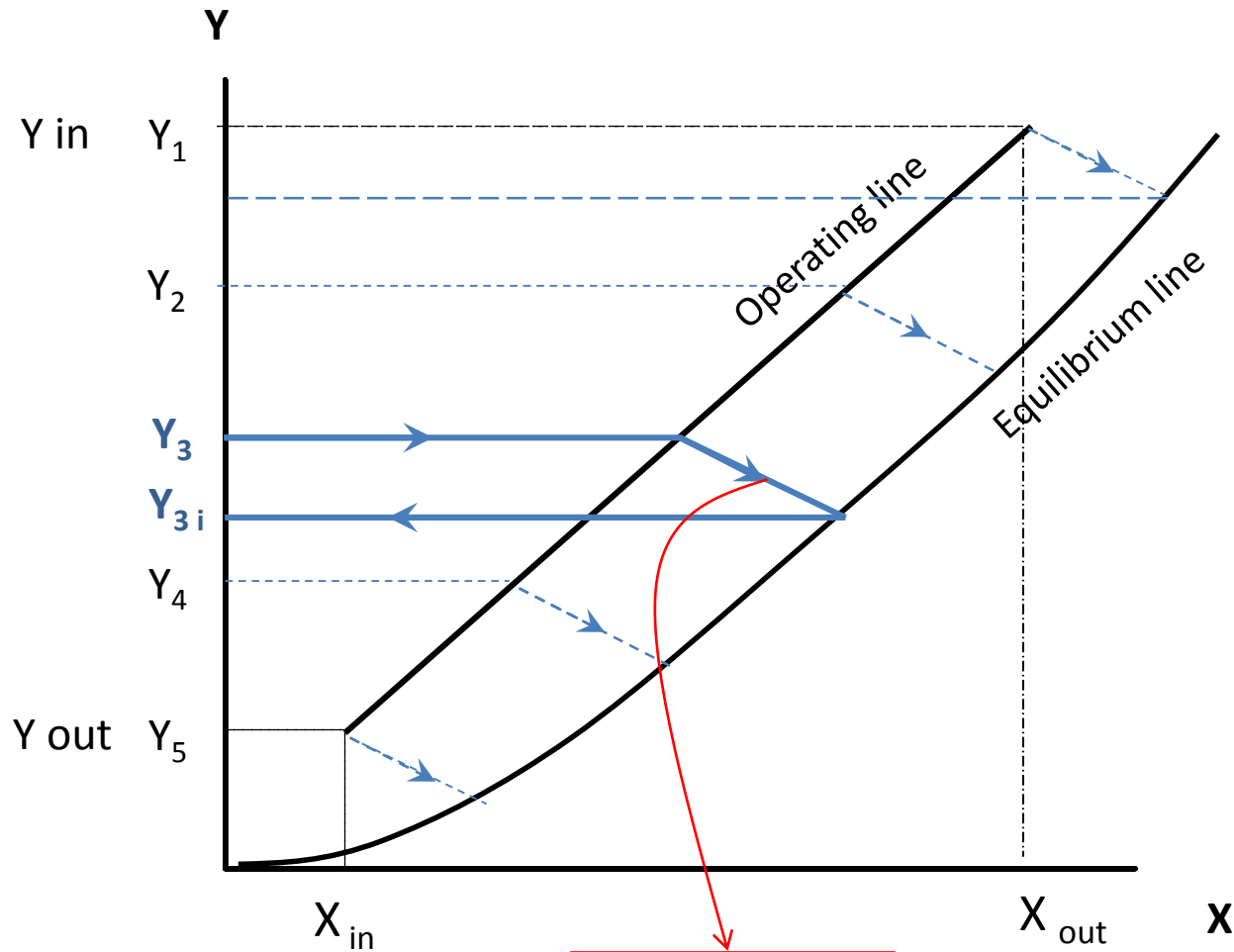
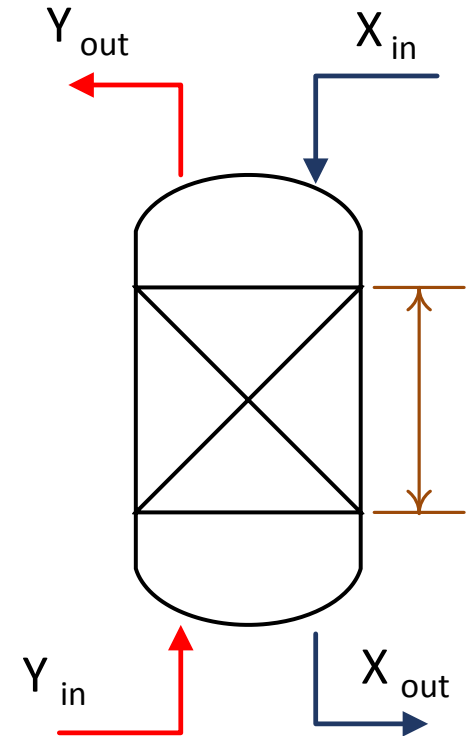


Figure 6.31 Interface composition in terms of the ratio of mass-transfer coefficients.

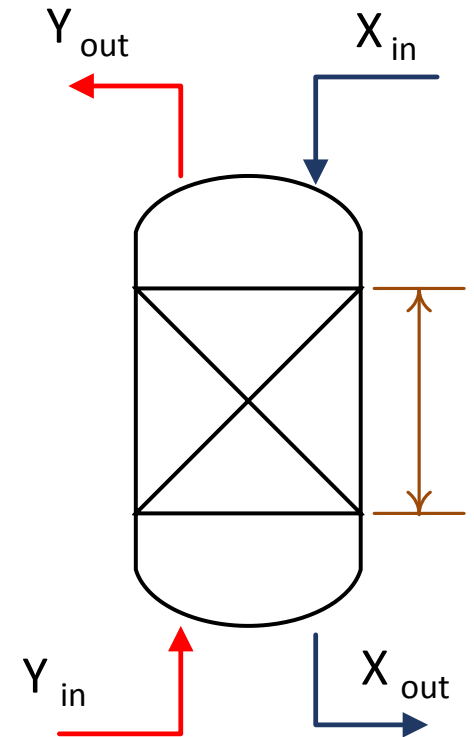
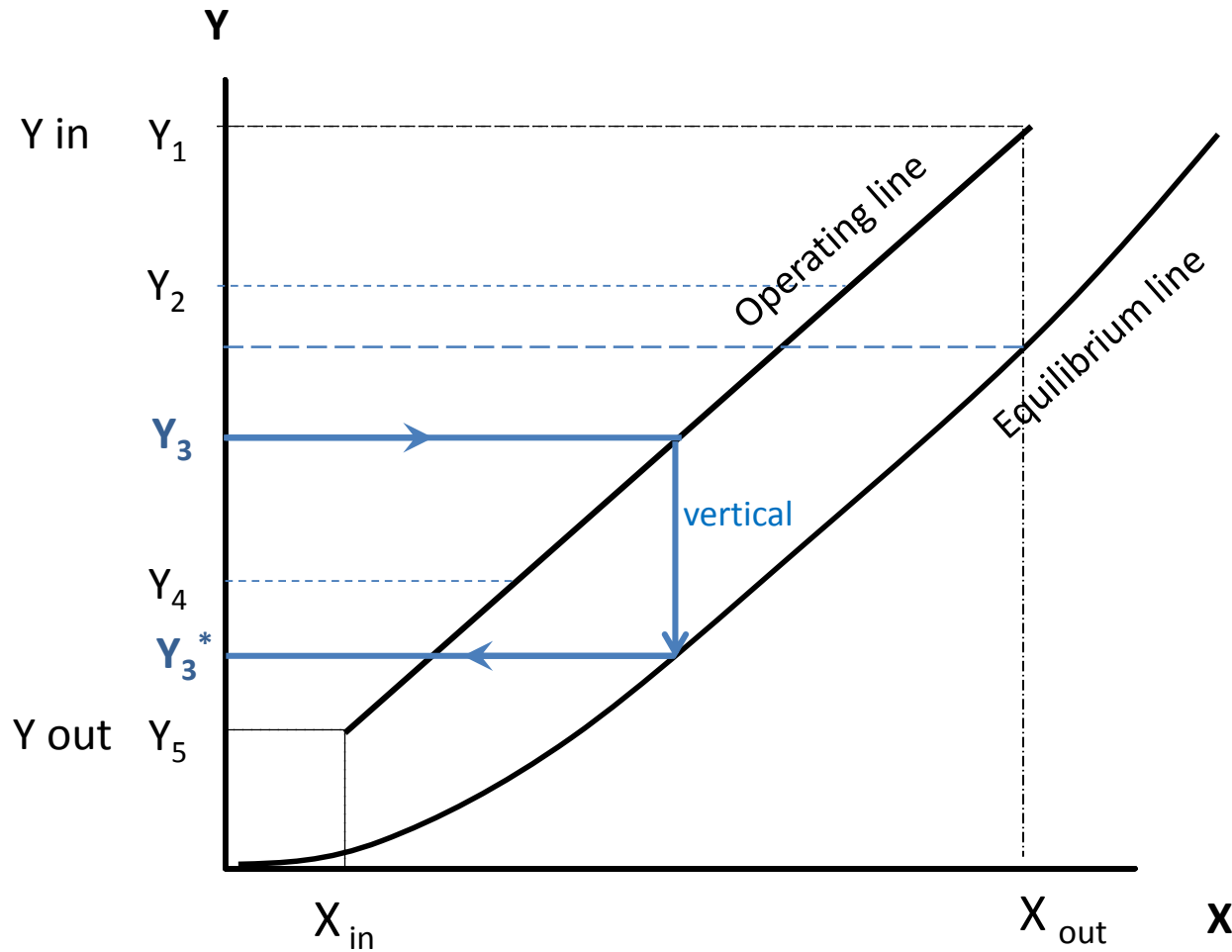
Counter-current Absorption (local gas phase)



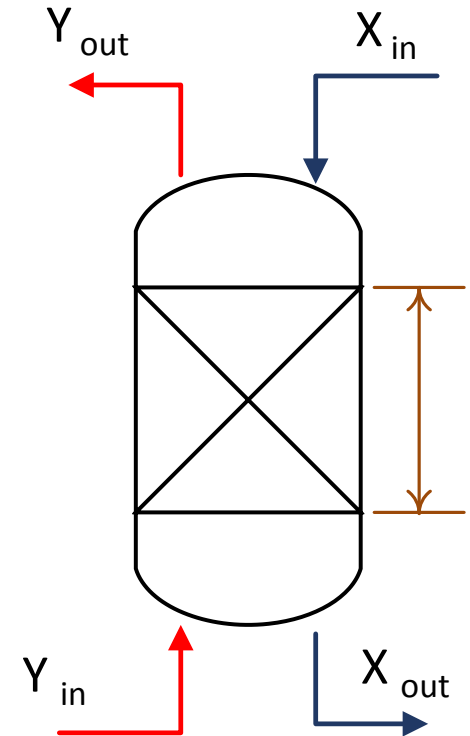
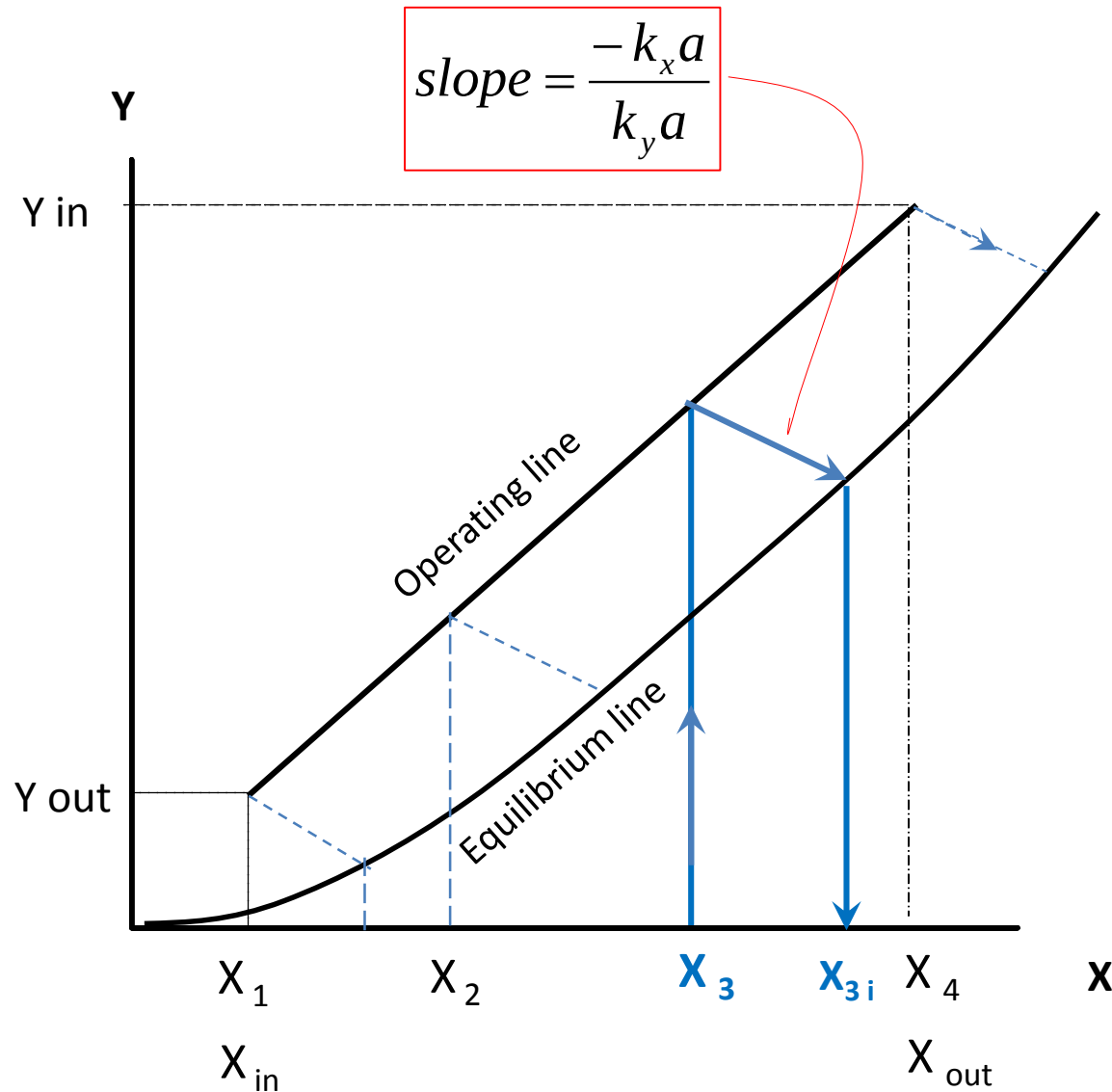
$$slope = \frac{-k_x a}{k_y a}$$



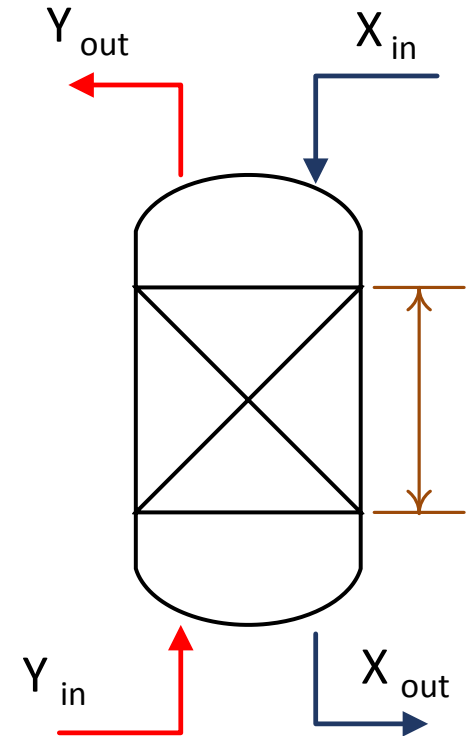
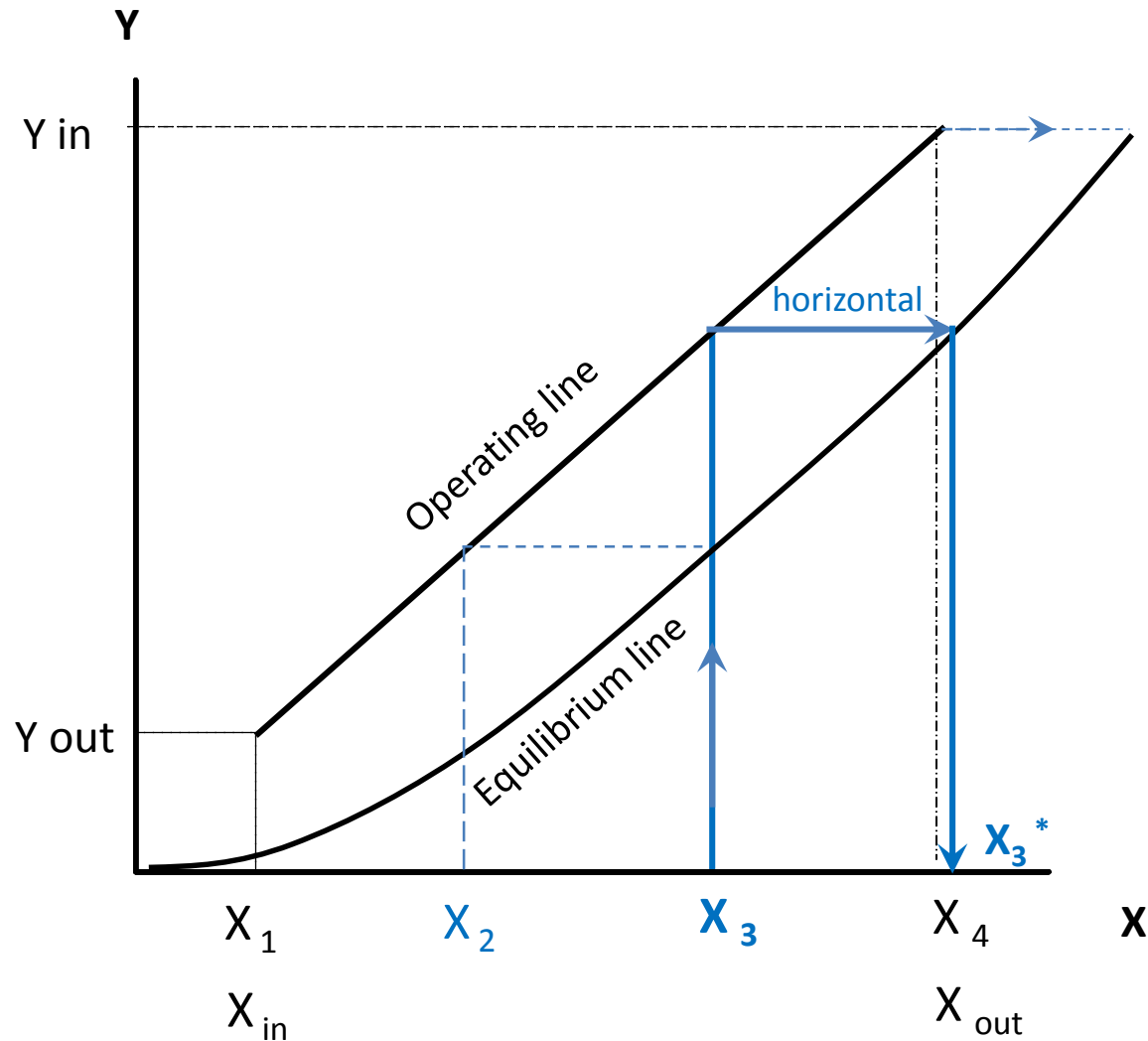
Counter-current Absorption (overall gas phase)



Counter-current Absorption (local liquid phase)



Counter-current Absorption (overall liquid phase)



Exercise 6.24

Subject: Absorption of SO_2 from air into water in an existing packed column.

Given: Feed gas flow rate of 0.062 kmol/s containing 1.6 mol% SO_2 . Absorbent is 2.2 kmol/s of pure water. Packed column is 1.5 m² in cross sectional area and packed with No. 2 plastic super Intalox saddles to a 3.5-m height. Exit gas contains an SO_2 mole fraction of 0.004. Operating pressure is 1 atm. At operating temperature, equilibrium curve for SO_2 is $y = Kx = 40x$

Assumptions: No stripping of water. No absorption of air.

Find: (a) $L/L_{\min}$
(b) N_{OG} and N_t
(c) H_{OG} and HETP
(d) $K_G a$

Note: This exercise (from Seader and Henley) was solved using an equation based on a certain approximation. You need to re-solve it graphically using Simpson's rule and compare the results.

(a) From Eq. (6-11), $L'_{\min} = V'K(\text{fraction absorbed}) = 0.061(40)(0.75) = 1.83 \text{ kmol/s}$

Therefore, $L/L'_{\min} = 2.2/1.83 = 1.20$

(b) Take $A = L/KV = 2.2/[(40)(0.062)] = 0.887$, From Eq. (6-13), $0.75 = \frac{0.887^{N+1} - 0.887}{0.887^{N+1} - 1}$

Solving, $N_t = 4$. For N_{OG} , use Eq. (6-89) with $y_{\text{in}} = 0.016$, $y_{\text{out}} = 0.004$, $x_{\text{in}} = 0.0$,

$$N_{OG} = \frac{\ln \left\{ \left[\frac{0.887 - 1}{0.887} \right] \left[\frac{0.016}{0.004} \right] + \frac{1}{0.887} \right\}}{(0.887 - 1)/0.887} = 3.78$$

(c) Given height of packing = 3.5 m = l_T

From Eq. (6-73), $HETP = l_T / N_t = 3.5/4 = 0.875$ m

From Eq. (6-89), $H_{OG} = l_T / N_{OG} = 3.5/3.78 = 0.926$ m

(d) From Table 6.7, $H_{OG} = \frac{V}{K_G a P S}$ Therefore, $K_G a = \frac{V}{H_{OG} P S} = \frac{0.062}{(0.926)(1)(1.5)}$
 $= 0.045$ kmol/s-m³-atm

Stripping Exercise

Wankat 15D8

We wish to strip SO_2 from water using air at 20C. The inlet air is pure. The outlet water contains 0.0001 mole fraction SO_2 , while the inlet water contains 0.0011 mole fraction SO_2 . Operation is at 855 mmHg and $L/V = 0.9 \times (L/V)_{\max}$. Assume $H_{\text{OL}} = 2.76$ feet and that the Henry's law constant is 22,500 mmHg/mole frac SO_2 .

Calculate the packing height required.

Solution

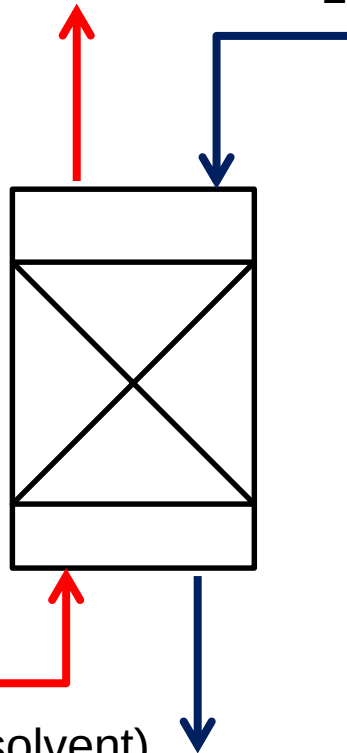
$T = 20^\circ\text{C}$

$P = 855 \text{ mmHg}$

Water

L

$$x_{\text{in}} = 0.0011 \\ = 11 \times 10^{-4}$$



Air (solvent)

V

$$y_{\text{in}} = 0$$

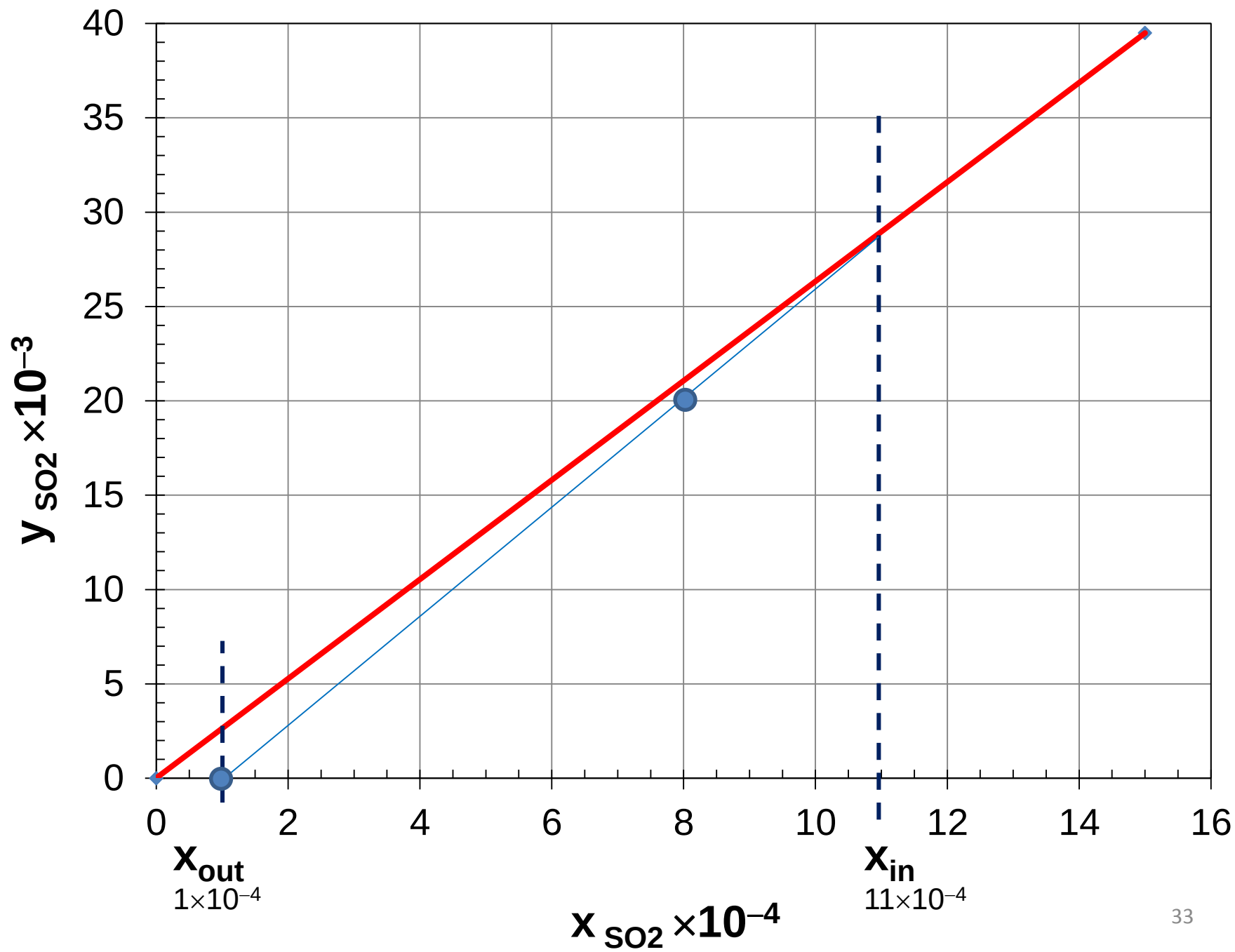
$$x_{\text{out}} = 0.0001 \\ = 1 \times 10^{-4}$$

- $P_{\text{tot}} = 855 \text{ mmHg}$
 - $H = 22,500 \text{ mmHg SO}_2 / \text{mole frac SO}_2$
 - $p_{\text{SO}_2} = H \ x_{\text{SO}_2}$
 - $y_{\text{SO}_2} P_{\text{tot}} = H \ x_{\text{SO}_2}$
- $$\Rightarrow y_{\text{SO}_2} = (H / P_{\text{tot}}) \ x_{\text{SO}_2}$$
- or $y_{\text{SO}_2} = m \ x_{\text{SO}_2}$
- where $m = (H / P_{\text{tot}}) = 22,500 / 855$
 $= 26.3$ (used to draw equilibrium data)

**Draw over the range of interest,
 i.e., from $x=0$ to $x= 11 \times 10^{-4}$**

$$\text{at } x=0 \Rightarrow y=0$$

$$\text{at } x= 11 \times 10^{-4} \Rightarrow y = 26.3 * 11 \times 10^{-4} \\ = 0.02893 = 28.93 \times 10^{-4}$$



$$\blacksquare V(y_{\text{out}} - y_{\text{out}}) = L(x_{\text{in}} - x_{\text{out}}) \Rightarrow V(y_{\text{out}} - 0) = L(11 \times 10^{-4} - 1 \times 10^{-4})$$

$$y_{\text{out}} = 10 \times 10^{-4} (L/V)$$

$$(L/V) = 0.9 (L/V)_{\text{max}}$$

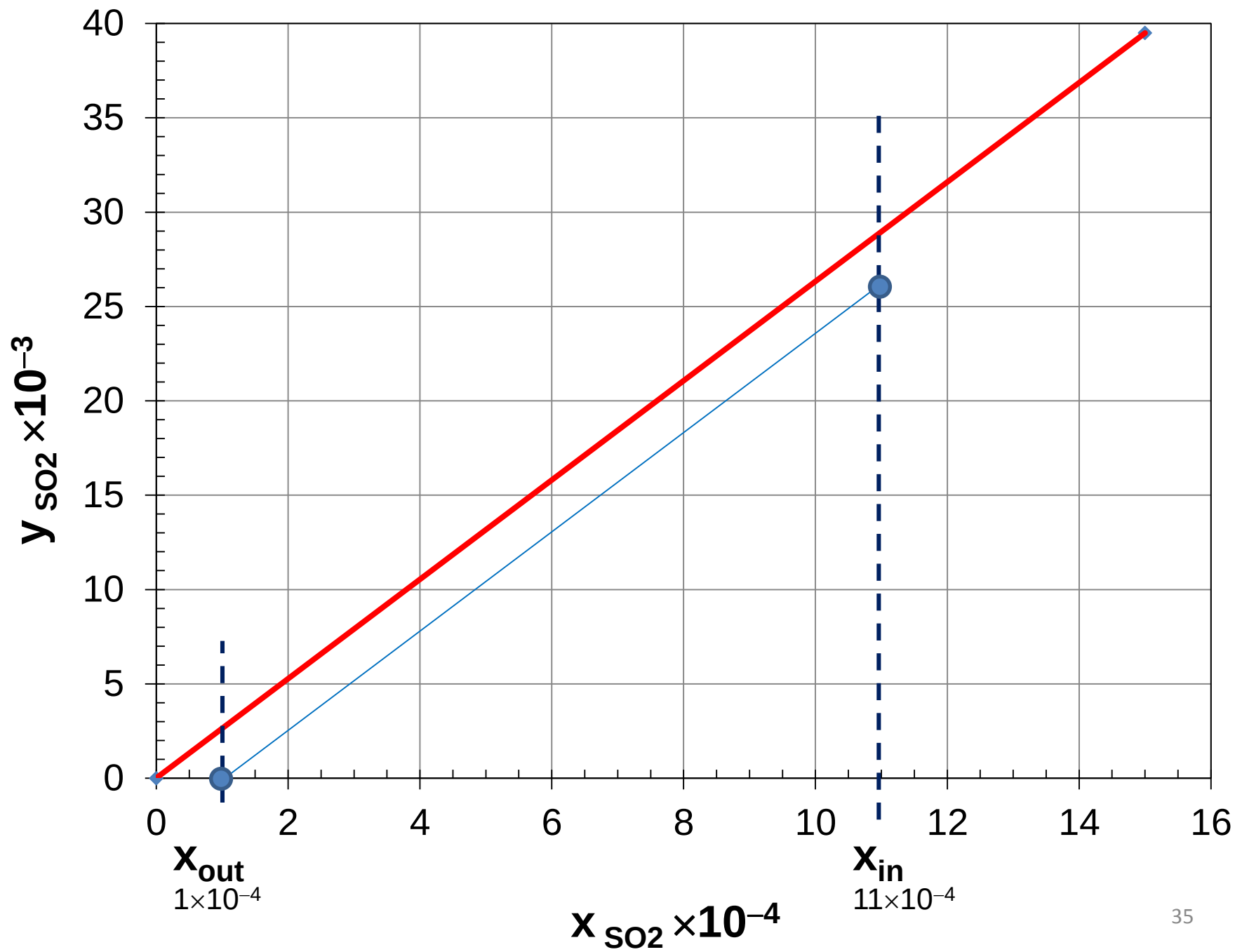
From pinch point and drawing, $(L/V)_{\text{max}} = \text{slope} = 29.29$

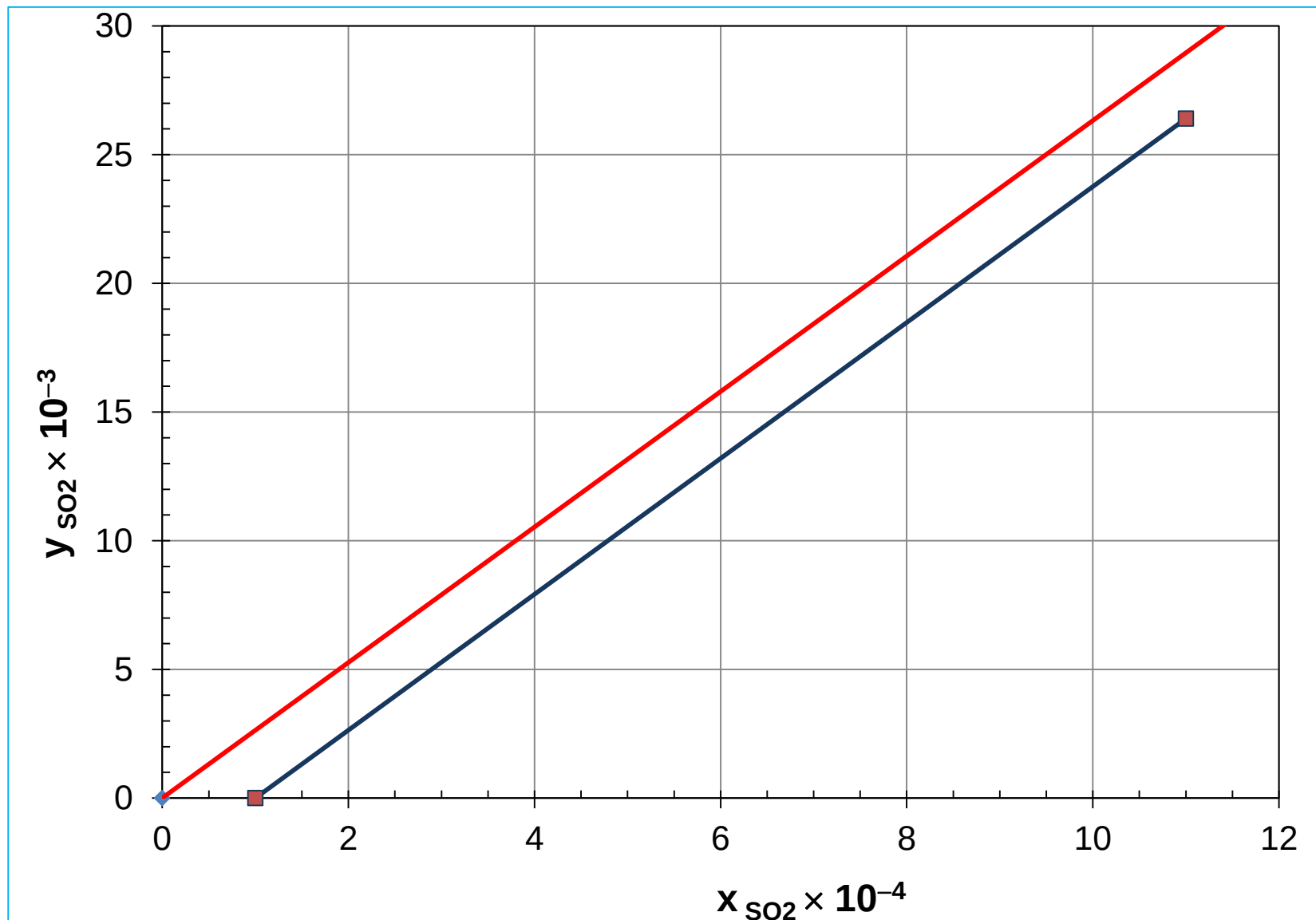
$$\Rightarrow (L/V) = 0.9 \times 29.29 = 26.36$$

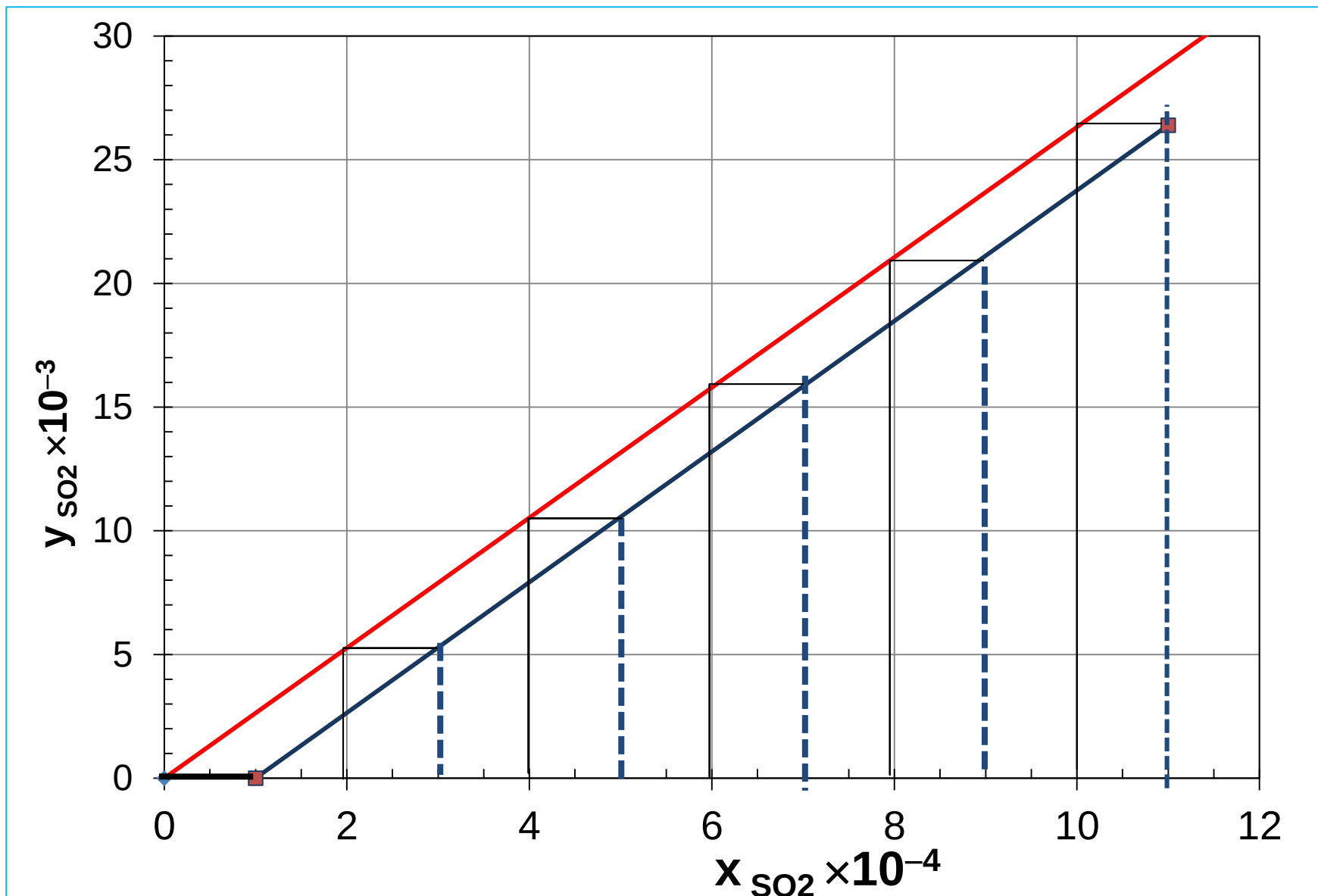
$$y_{\text{out}} = 10 \times 10^{-4} (L/V) = 10 \times 10^{-4} \times 26.36$$

$$\Rightarrow \mathbf{y_{\text{out}} = 0.02636 = 26.36 \times 10^{-3}}$$

Draw actual operating line







x	x*	1/(x-x*)
1.0E-4	0	10,000
3.0E-04	2.0E-04	10,000
5.0E-04	4.0E-04	10,000
7.0E-04	6.0E-04	10,000
9.0E-04	8.0E-04	10,000
1.1E-03	1.0E-03	10,000

Apply a graphical or numerical method for evaluating N_{OL}

$$\int_{x_{Aout}=0.0001}^{x_{Ain}=0.0011} \frac{dx}{(x_A - x_A^*)}$$

For example, we can use Simpson's rule. The 7 point Simpson's rule defined as follows:

$$\int_{X_0}^{X_6} f(X) dX = \frac{h}{3} [f(X_0) + 4f(X_1) + 2f(X_2) + 4f(X_3) + 2f(X_4) + 4f(X_5) + f(X_6)]$$

$$h = \frac{(X_6 - X_0)}{6}$$

$$\int_{X_0}^{X_6} f(X) dX = \frac{(X_6 - X_0)}{6 \times 3} [f(X_0) + 4f(X_1) + 2f(X_2) + 4f(X_3) + 2f(X_4) + 4f(X_5) + f(X_6)]$$

$$\int_{X_0}^{X_6} f(X) dX = \frac{(X_6 - X_0)}{6 \times 3} [f(X_0) + 4f(X_1) + 2f(X_2) + 4f(X_3) + 2f(X_4) + 4f(X_5) + f(X_6)]$$

$$\int_{x_{Aout}=0.0001}^{x_{Ain}=0.0011} \frac{dx}{(x_A - x_A^*)} \quad f(X) = \frac{1}{(x - x^*)}$$

Substituting values from Table gives $N_{OL} = 9.5$.

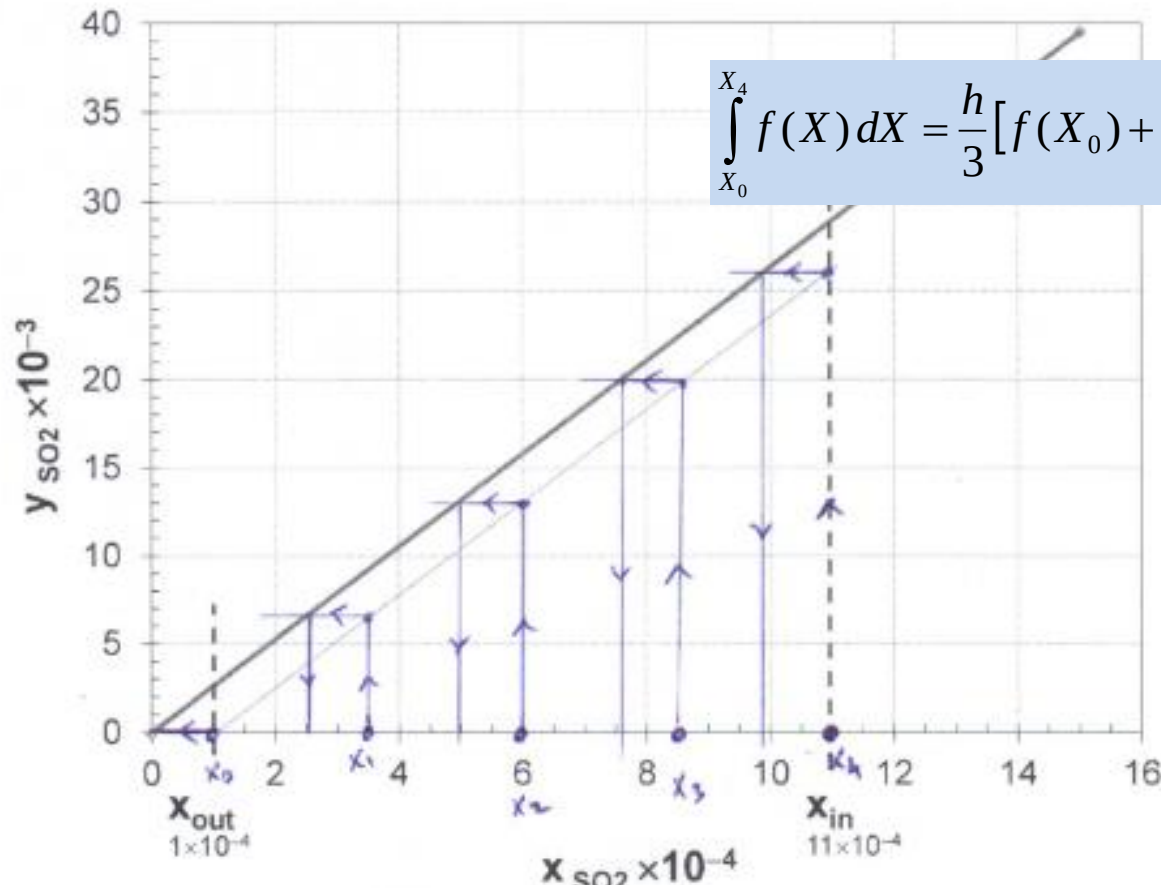
$$Z = H_{OL}(\text{given}) \times N_{OL}(\text{calculated}) = 2.76 \times 9.5$$

$$\Rightarrow \underline{\underline{Z = 26.22 \text{ ft}}}$$

5-point method

$$\int_{X_0}^{X_4} f(X) dX = \frac{h}{3} [f(X_0) + 4f(X_1) + 2f(X_2) + 4f(X_3) + f(X_4)]$$

$$h = \frac{(X_4 - X_0)}{4}$$



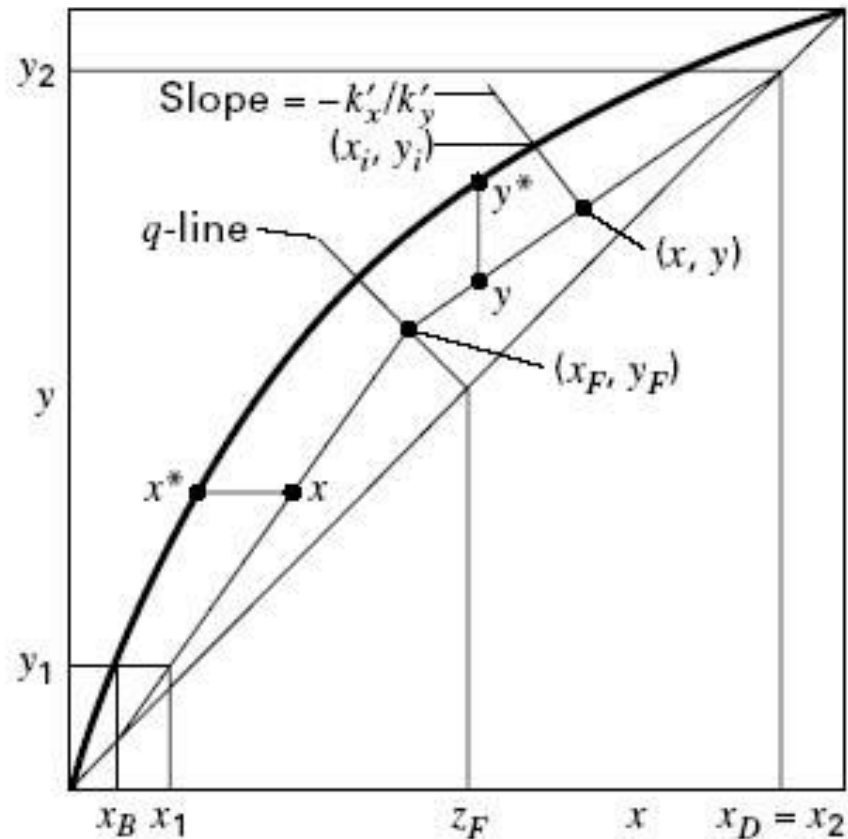
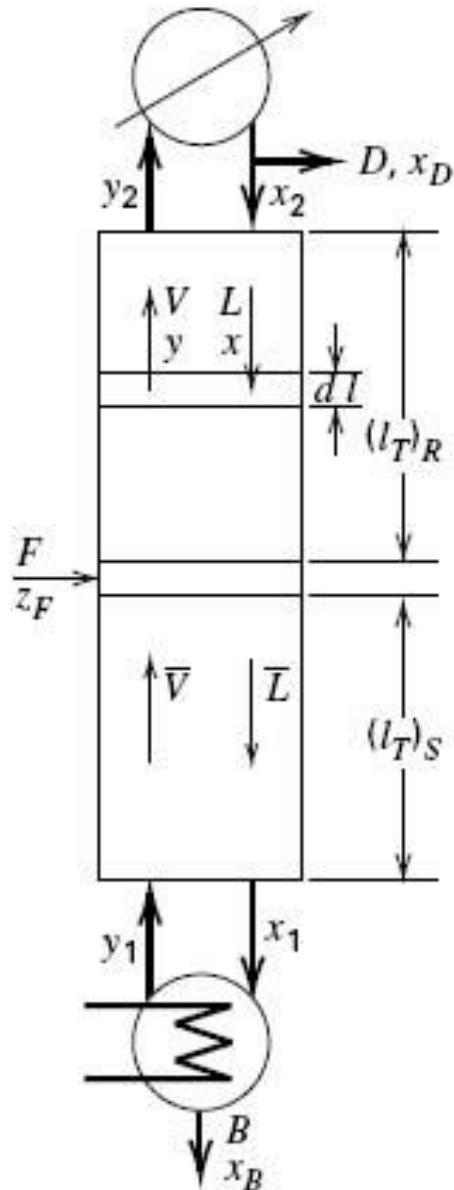
Pay attention to accuracy of drawing and obtaining data.

Grades will be subtracted in case of hand drawing!

	x	x*	f(x) = 1/(x-x*)
0	1.0E-4	0	10,000
1	3.5 x 10 ⁻⁴	2.5 x 10 ⁻⁴	10,000
2	6 x 10 ⁻⁴	5 x 10 ⁻⁴	10,000
3	8.5 x 10 ⁻⁴	7.5 x 10 ⁻⁴	10,000
4	1.1E-4	10 x 10 ⁻⁴	10,000

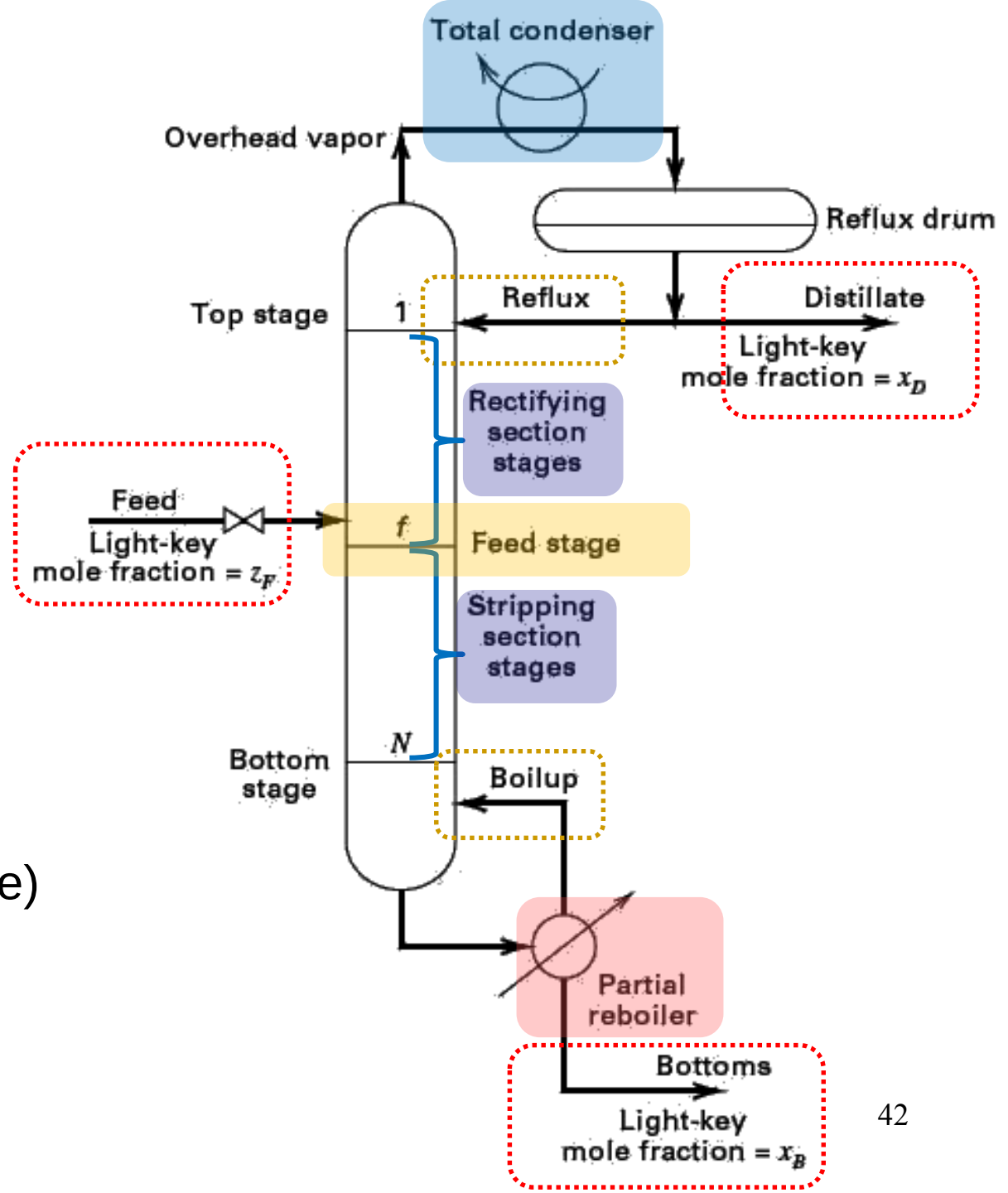
Distillation in a Packed Column

Read Section 15.2 Wankat 2nd Ed.
Or Section 16.1 Wankat 3rd Ed.



(b)

1. Feed
2. Distillate
3. Bottom
4. Reflux
5. Boilup
6. Rectifying section
7. Striping section
8. Condenser
9. Re-boiler
10. Tray (plate or stage)
11. Number of Trays
12. Feed tray



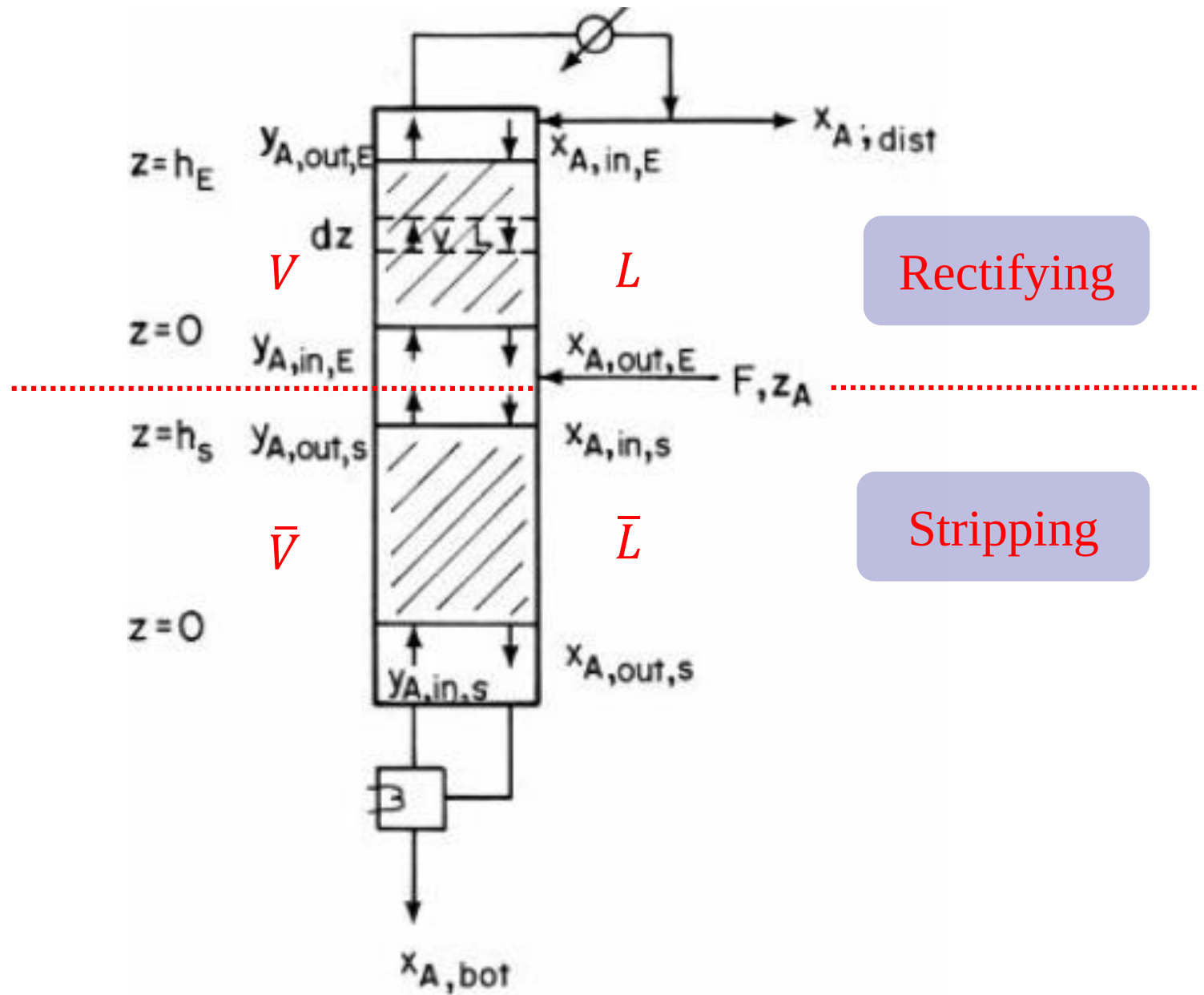
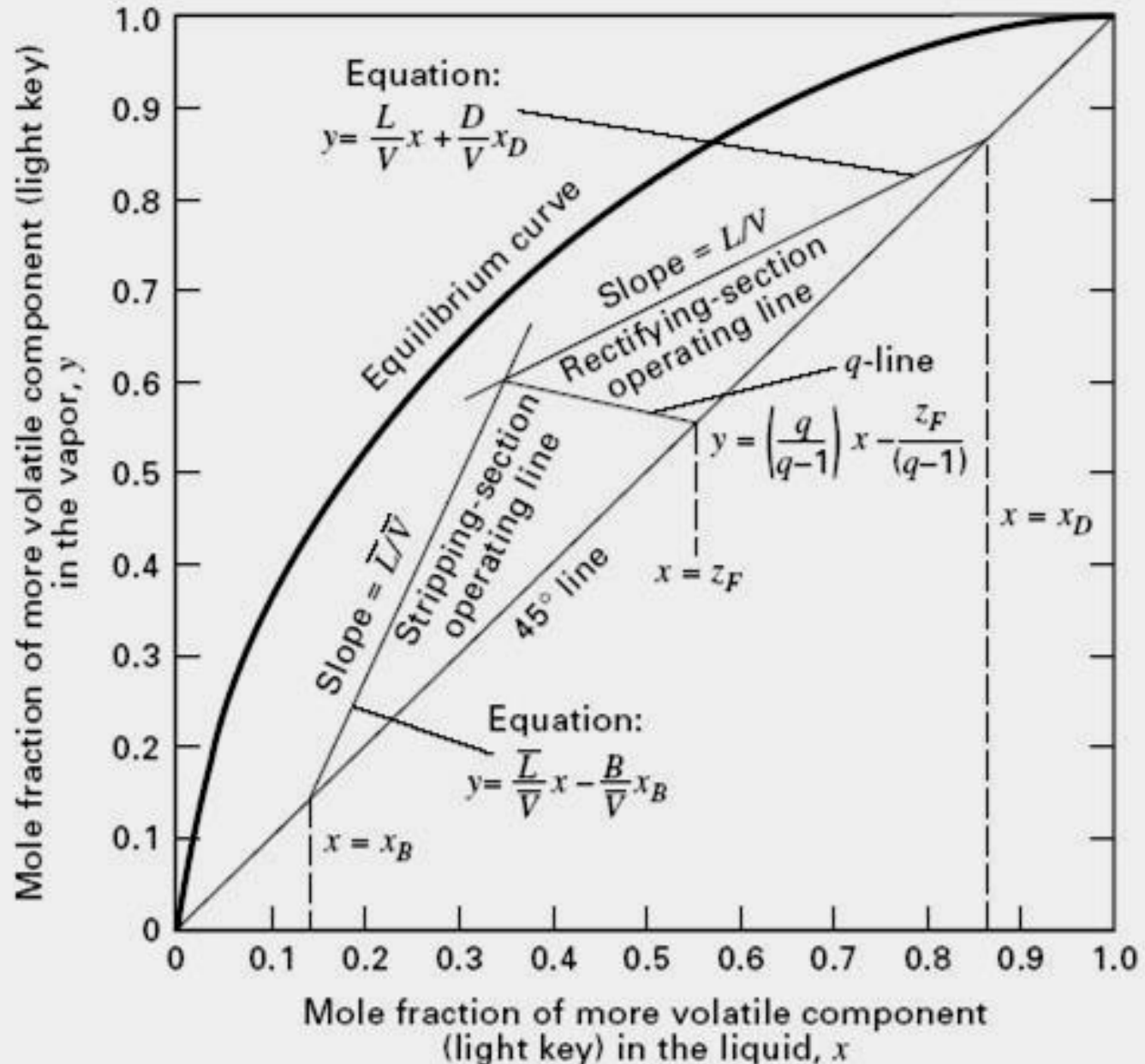


Figure 16-1. Packed distillation column

Equilibrium and Operating Lines

Graphical
Design
Method

Binary
mixtures

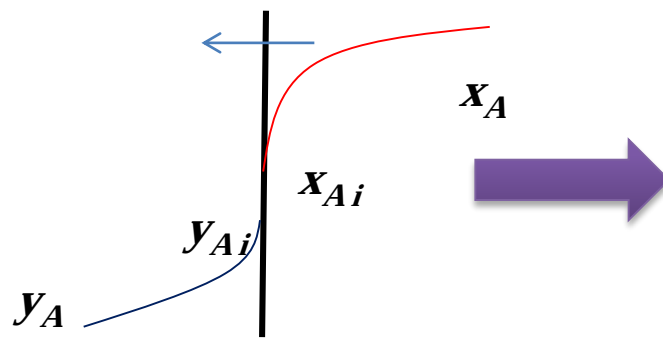


Rectifying section

HTU	NTU
$H_G = \frac{V}{k_y a A_c}$	$N_G = \int_{y_{in}}^{y_{out}} \frac{dy_A}{(y_{Ai} - y_A)}$
$H_L = \frac{L}{k_x a A_c}$	$N_L = \int_{x_{out}}^{x_{in}} \frac{dx_A}{(x_A - x_{Ai})}$
$H_{OG} = \frac{V}{K_y a A_c}$	$N_{OG} = \int_{y_{in}}^{y_{out}} \frac{dy_A}{(y_A^* - y_A)}$
$H_{OL} = \frac{L}{K_x a A_c}$	$N_{OL} = \int_{x_{in}}^{x_{out}} \frac{dx_A}{(x_A - x_A^*)}$
Slope of tie line	$\frac{(y_{Ai} - y_A)}{(x_{Ai} - x_A)} = \frac{-k_x a}{k_y a} = \frac{-L}{V} \frac{H_G}{H_L}$

Stripping section

HTU	NTU
$H_G = \frac{\bar{V}}{k_y a A_c}$	$N_G = \int_{y_{in}}^{y_{out}} \frac{dy_A}{(y_{Ai} - y_A)}$
$H_L = \frac{\bar{L}}{k_x a A_c}$	$N_L = \int_{x_{out}}^{x_{in}} \frac{dx_A}{(x_A - x_{Ai})}$
$H_{OG} = \frac{\bar{V}}{K_y a A_c}$	$N_{OG} = \int_{y_{in}}^{y_{out}} \frac{dy_A}{(y_A^* - y_A)}$
$H_{OL} = \frac{\bar{L}}{K_x a A_c}$	$N_{OL} = \int_{x_{in}}^{x_{out}} \frac{dx_A}{(x_A - x_A^*)}$
Slope of tie line	$\frac{(y_{Ai} - y_A)}{(x_{Ai} - x_A)} = \frac{-k_x a}{k_y a} = \frac{-\bar{L}}{\bar{V}} \frac{H_G}{H_L}$



$$\frac{y_{Ai} - y_A}{x_{Ai} - x_A} = \frac{-k_x a}{k_y a} = \frac{L}{V} \frac{H_G}{H_L}$$

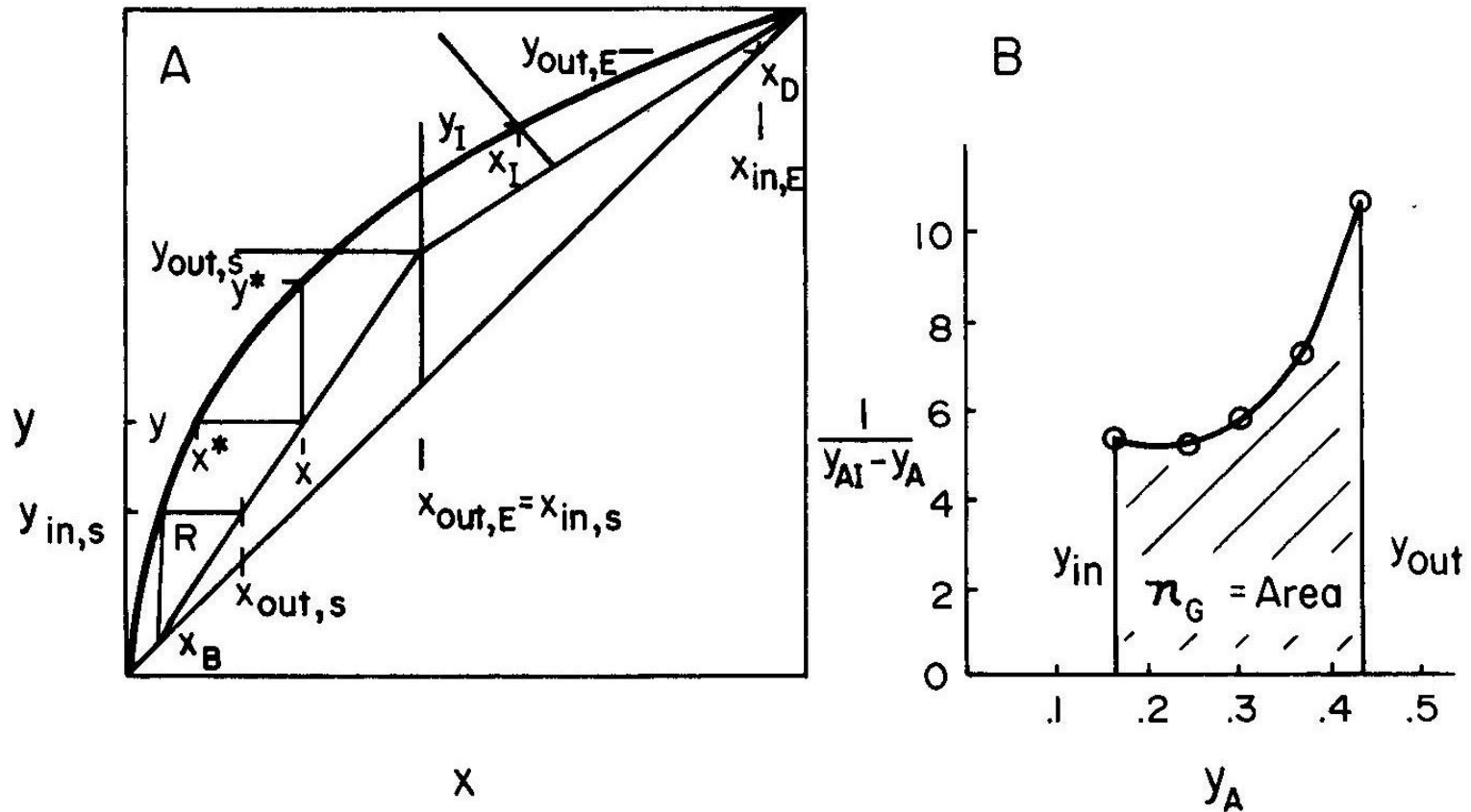


FIGURE 15-3. Analysis of number of transfer units; A) determination of equilibrium or interfacial values, B) graphical integration of Eq. (15-12b) shown for stripping section of Example 15-1

Example 15-1 Wankat (pages 109 and 509)

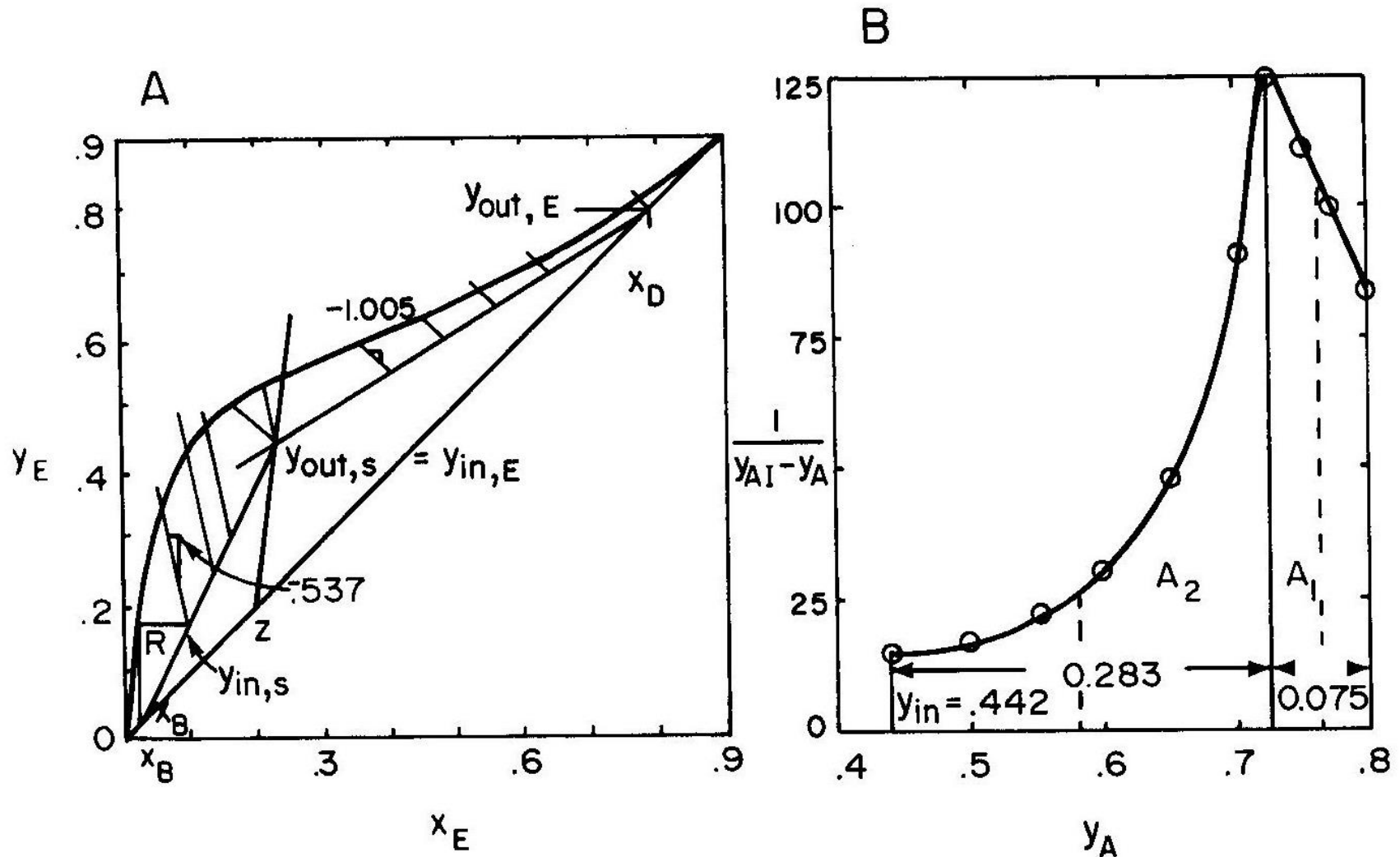
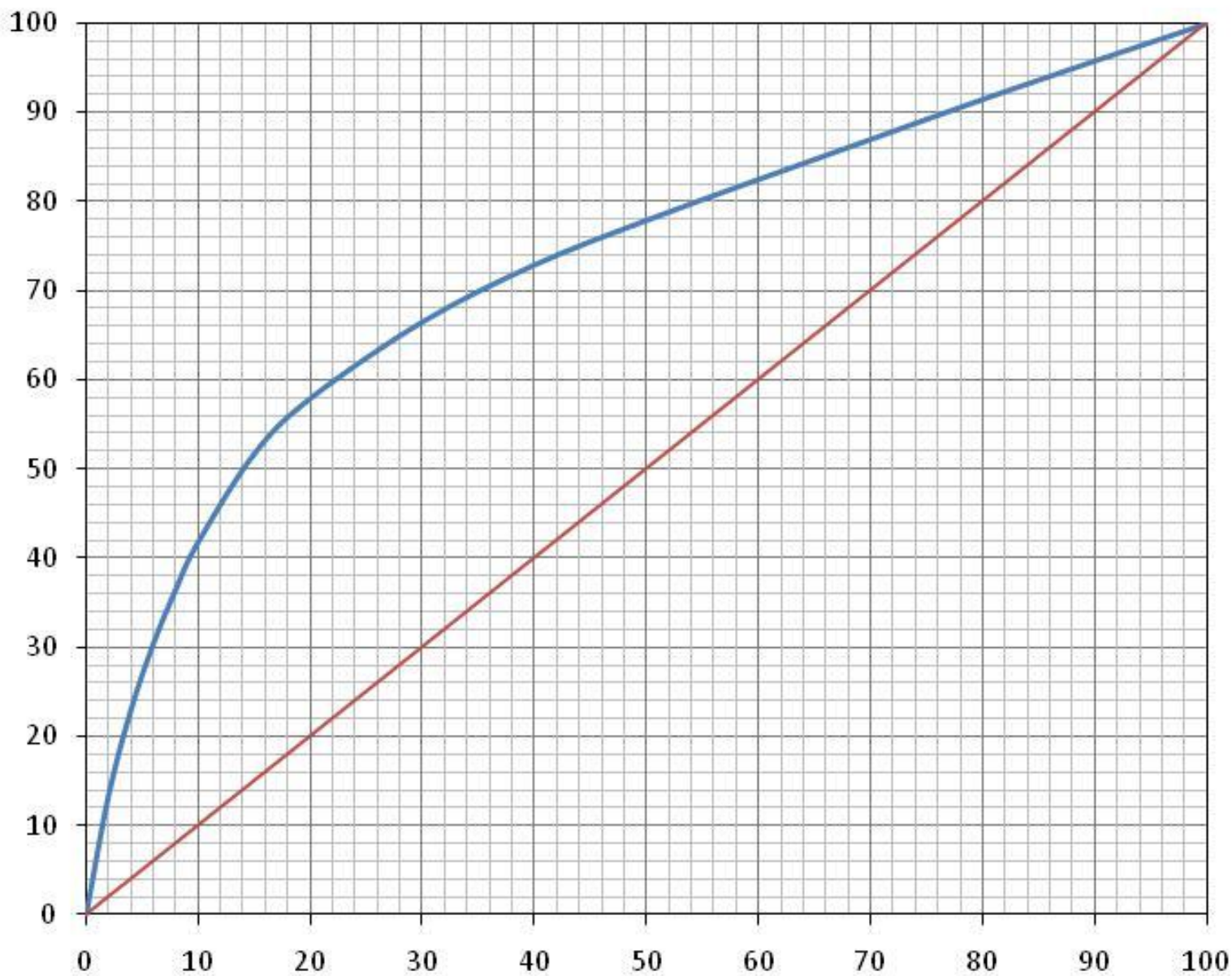


FIGURE 15-4. *Solution to Example 15-1; A) determination of $y_{AI} = y_{EI}$, B) graphical integration for enriching section*

Distillation Exercise 15D4 (Wankat)

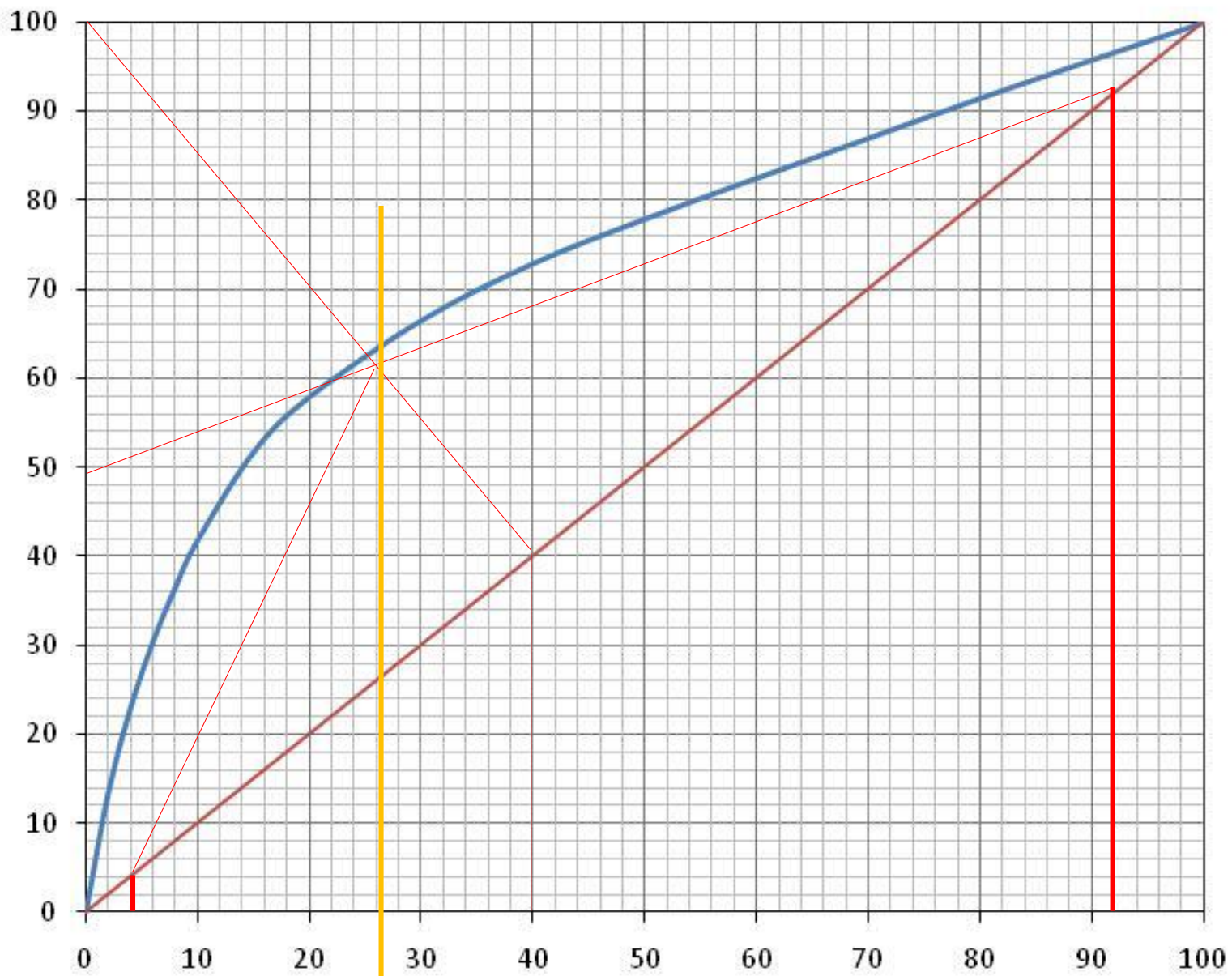
D4.* A distillation column is separating a feed that is 40 mole % methanol and 60 mole % water. The two-phase feed is 60% liquid. Distillate product should be 92 mole % methanol, and bottoms 4 mole % methanol. A total reboiler and a total condenser are used. Reflux is a saturated liquid. Operation is at 101.3 kPa. Assume CMO, and use $L/D = 0.9$. Under these conditions $H_G = 1.3$ feet and $H_L = 0.8$ feet in both the enriching and stripping sections. Determine the required heights of both the enriching and stripping sections. Equilibrium data are given in Table 2-7.

y Methanol



x Methanol

y Methanol



x Methanol

ya	yai	(yai-ya)	1/(yai-ya)
0.04	0.13	0.09	11.11
0.3225	0.455	0.1325	7.55
0.605	0.63	0.025	40.00
0.605	0.62	0.015	66.67
0.7625	0.8	0.0375	26.67
0.92	0.95	0.03	33.33

Diameter calculation of Packed Columns

- Read sections 10.7 to 10.9 Wankat (2nd or 3rd Ed.)