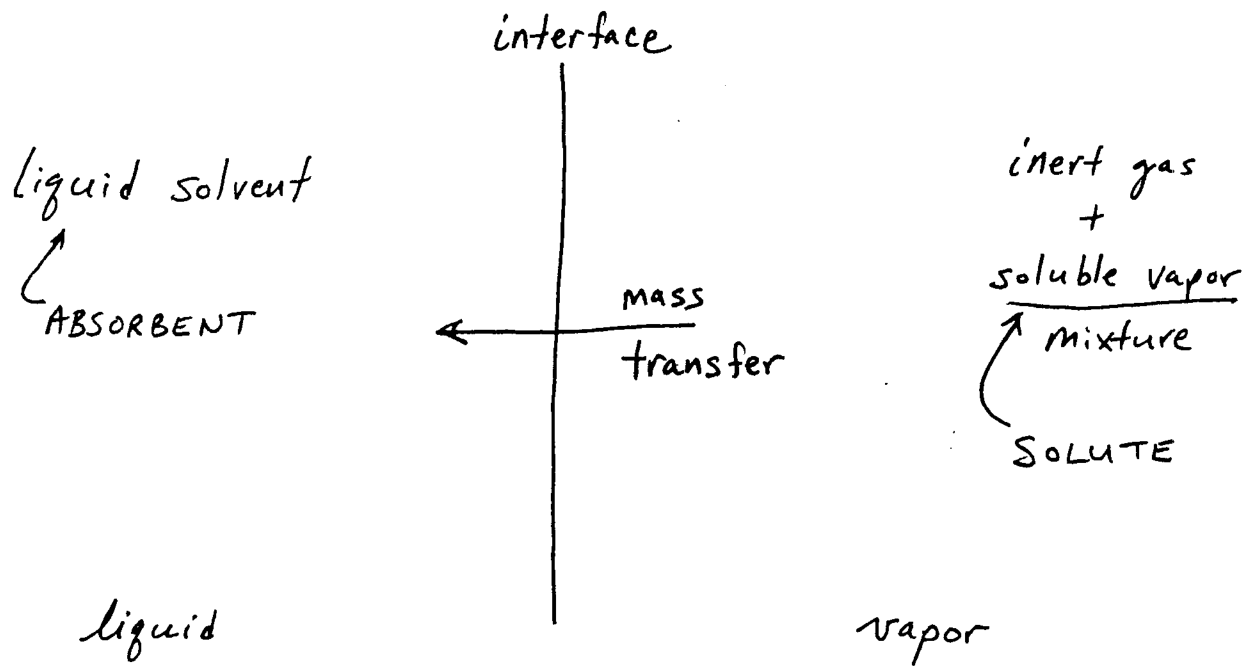
CHAPTER 6:

ABSORPTION AND STRIPPING OF DILUTE MIXTURES

WHAT IS ABSORPTION?



HOW DO WE GET THE SEPARATION?

→ ADDED A MASS SEPARATING AGENT
(Liquid Solvent)

→ MASS TRANSFER by Concentration Gradient Driving Force

(GAS PHASE → LIQUID PHASE)

Key examples:

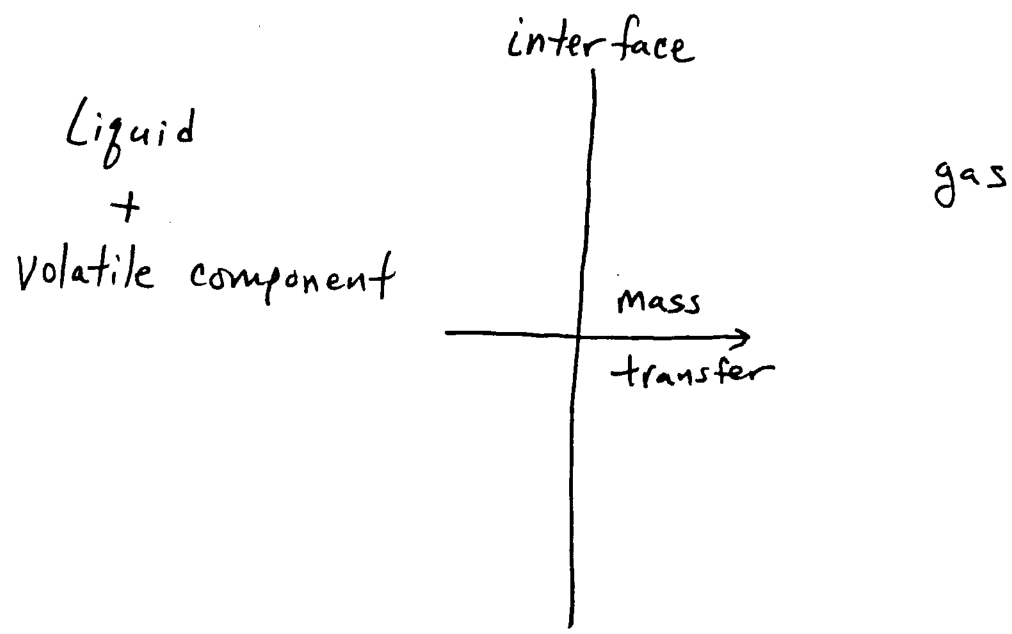
1) CO_2 and H_2S Removal from natural gas

(liquid solvent = solution of amines or alkaline salts)

2) NH_3 Removal from air

(liquid solvent = water)

WHAT IS <u>DE</u>SORPTION (STRIPPING)?



HOW DO WE GET THE SEPARATION?

SAME AS ABSORPTION, JUST OPPOSITE DIRECTION

(LIQUID PHASE → GAS PHASE)

[redacted]

Key examples:

1) VOC Removal from water
   (gas = air)

2) Solvent deoxygenation
   (gas = N_2)

3) Absorbent regeneration
   (gas = varied)

ABSORPTION AND STRIPPING FACTORS:

→ EQUILIBRIUM OPERATION (between 2 phases)

GAS	IDEAL	NONIDEAL
LIQUID	IDEAL	NONIDEAL

HOW DO WE RELATE COMPOSITIONS IN EACH PHASE?

Recall, MODIFIED RAOULT'S LAW

$$y_i P = x_i \gamma_i P_i^{sat}$$

$$\frac{y_i}{x_i} = K_i = \frac{\gamma_i P_i^{sat}}{P}$$

from solution thermodynamics...

P_i^{sat} from Antoine Equation

γ_i from activity coefficient model

P given or measured

if we know composition (x_i, y_i), then know K_i

$K_i = f(x, y)$ and different at each stage $\Rightarrow$

Absorption Factor will be stage specific.

$$A_N = \frac{L}{VK}$$

Absorption factor for stage N.

NOTE: WE HAVE MADE AN ASSUMPTION

L & V are constant.

Reasonable?

Remember, we are absorbing solute from dilute solution. Since only the solute is transferred, then L + V (molar flow rates) are approximately constant.

$$S_N = \frac{VK}{L} = \frac{1}{A_N}$$

Stripping factor for stage N.

Now, K set by composition ... what happens to A_N & S_N when $V + L$ change.

A_N: **Case 1** V increases L constant

$\Rightarrow A_N \downarrow$

Why? Less contact time

Case 2 V decreases L constant

$\Rightarrow A_N \uparrow$

Why? Higher residence time

Case 3 V constant L increases

$\Rightarrow A_N \uparrow$

Why? more liquid $\Rightarrow$ higher driving force
(does not get as concentrated in soluble component)

Case 4 V constant L decreases

$\Rightarrow A_N \downarrow$

Why? less liquid $\Rightarrow$ lower driving force

(liquid gets concentrated faster w/ soluble vapor component and concentration gradient decreases)

Notice that all of this was very logical.
Can make similar analysis for desorption/stripping.

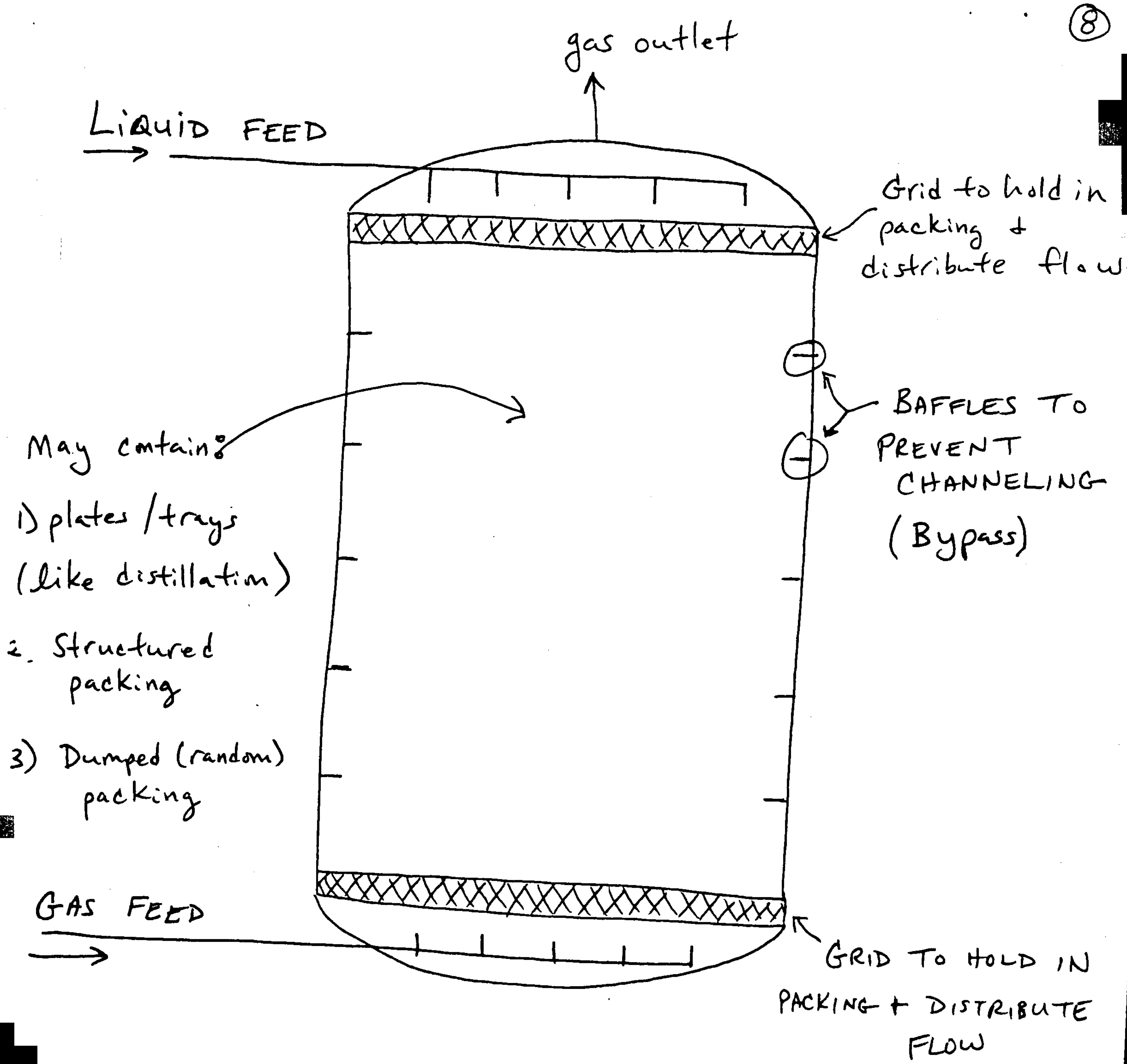
Different types of absorption:

Physical: movement of molecules from phase A to phase B. Still exist as the molecule in new phase.

Reactive: movement into new phase includes reaction in the new phase to a different type of molecule.
(can be irreversible or reversible)

Well, what do the columns look like?

→



<u>NOTICE:</u> <u>NO</u> CONDENSERS

<u>NO</u> REBOILERS

BIGGEST CONCERN IS PRESSURE DROP

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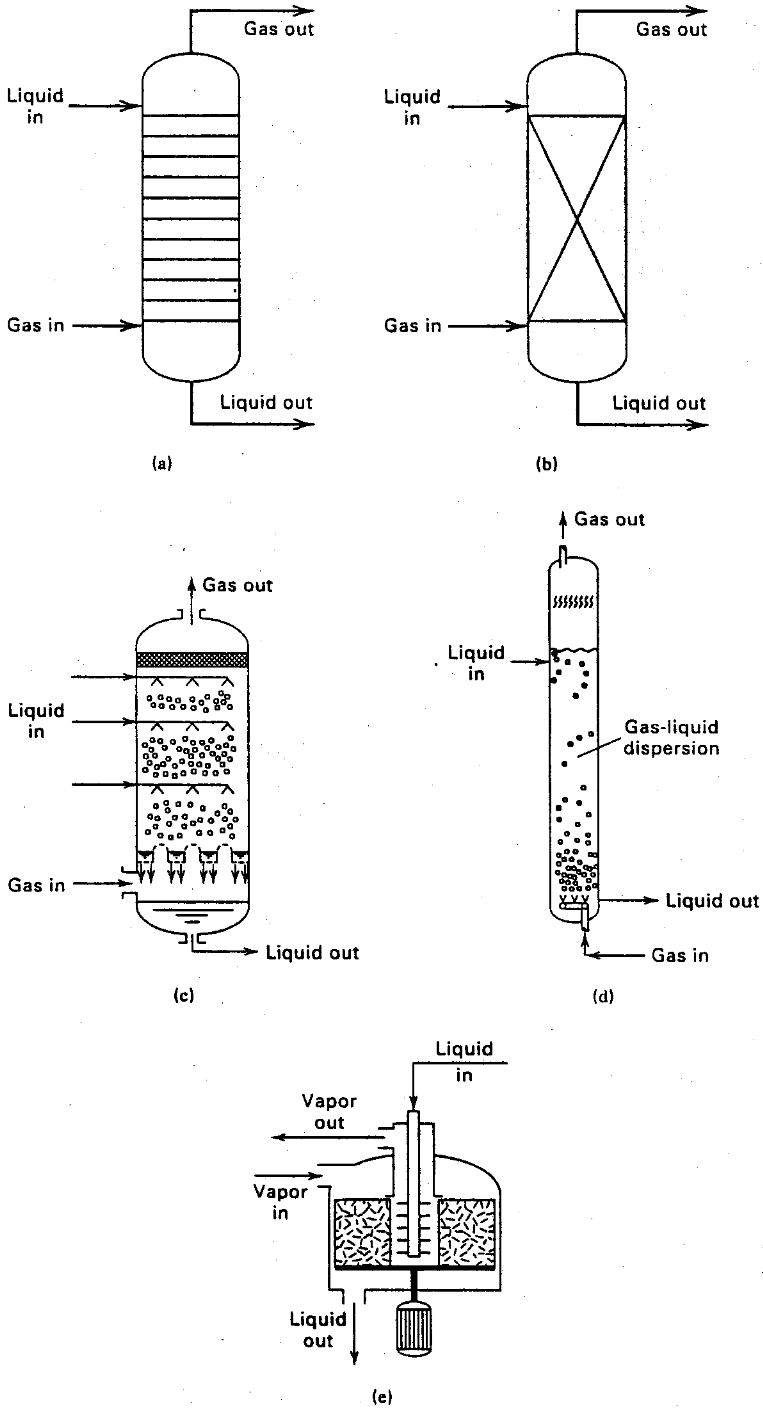

Figure 6.2 Industrial equipment for absorption and stripping: (a) trayed tower; (b) packed column; (c) spray tower; (d) bubble column; (e) centrifugal contactor.

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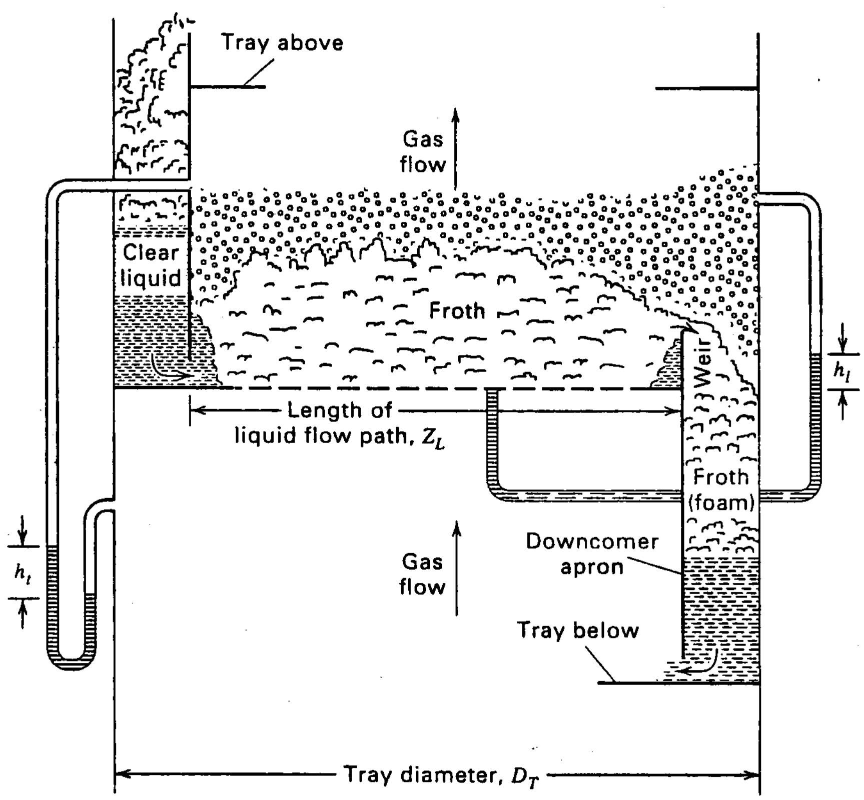

Figure 6.3 Details of a contacting tray in a trayed tower. [Adapted from B.F. Smith, *Design of Equilibrium Stage Processes*, McGraw-Hill, New York (1963).]

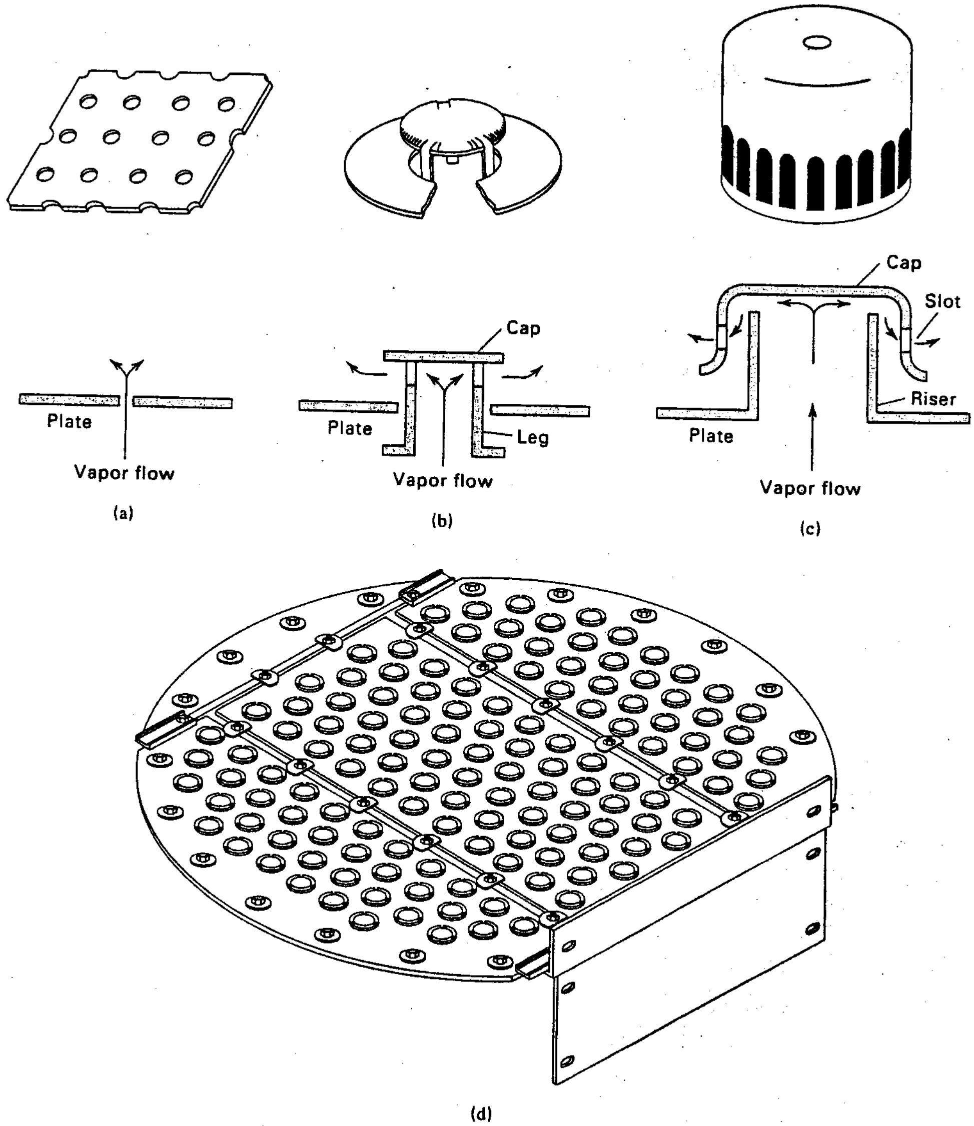

Figure 6.5 Three types of tray openings for passage of vapor up into liquid: (a) perforation; (b) valve cap; (c) bubble cap. (d) Tray with valve caps.

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

+ inclass demonstration

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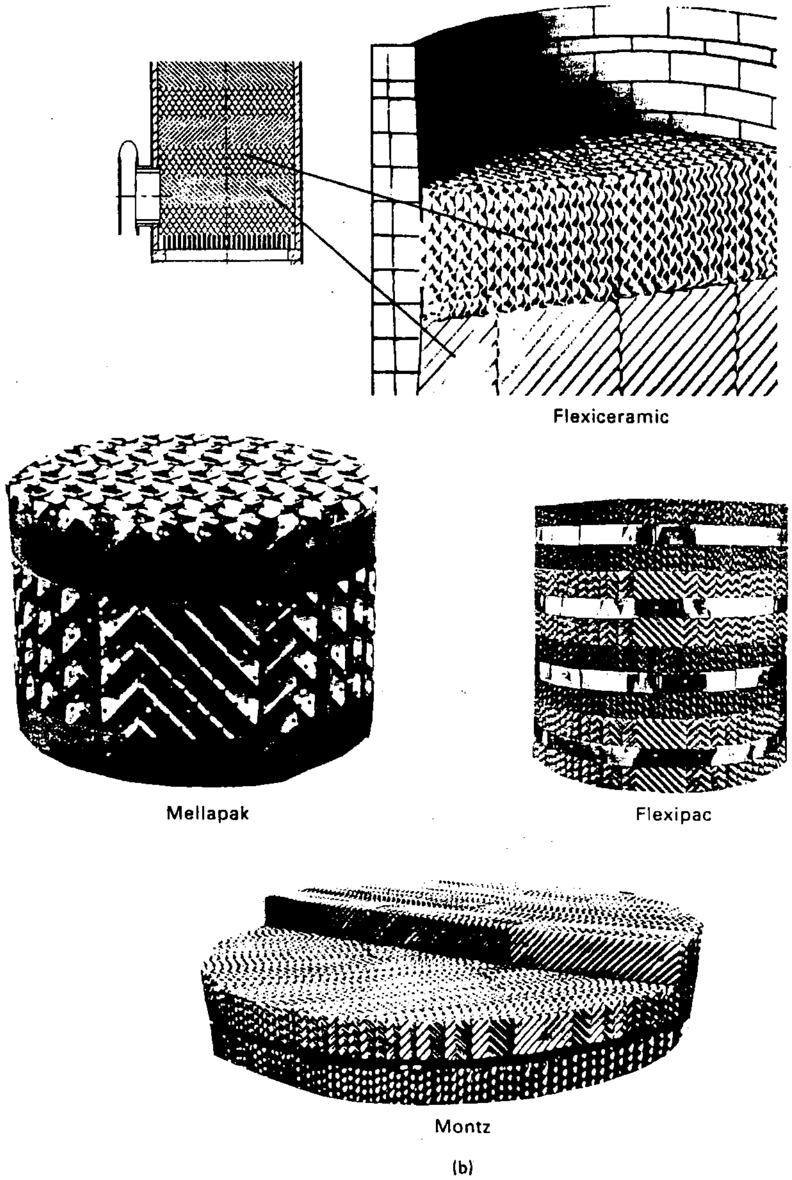

Figure 6.7 (*Continued*) (b) structured packing materials.

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NEXT TIME:

DESIGNING ABSORPTION TOWERS:

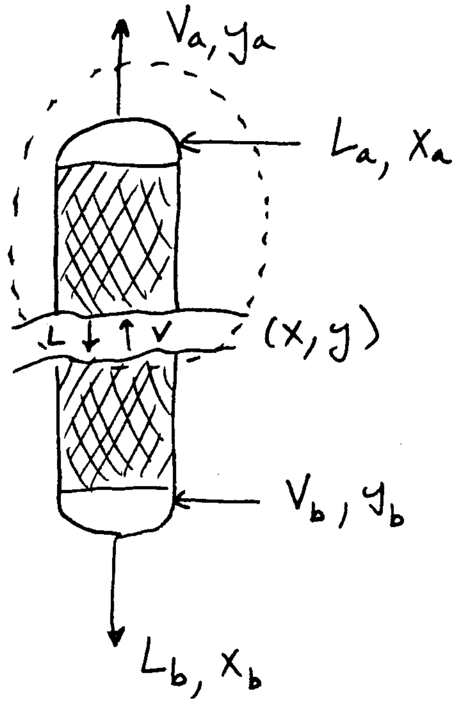
BASED ON TWO CONCEPTS:

(1) MATERIAL BALANCE MODEL

(2) FLOODING CALCULATION

OBJECTIVE:

FIND TOWER HEIGHT + DIAMETER



MATERIAL BALANCE:

(around top of column)

IN = OUT

$$yV + L_a x_a = y_a V_a + L x$$

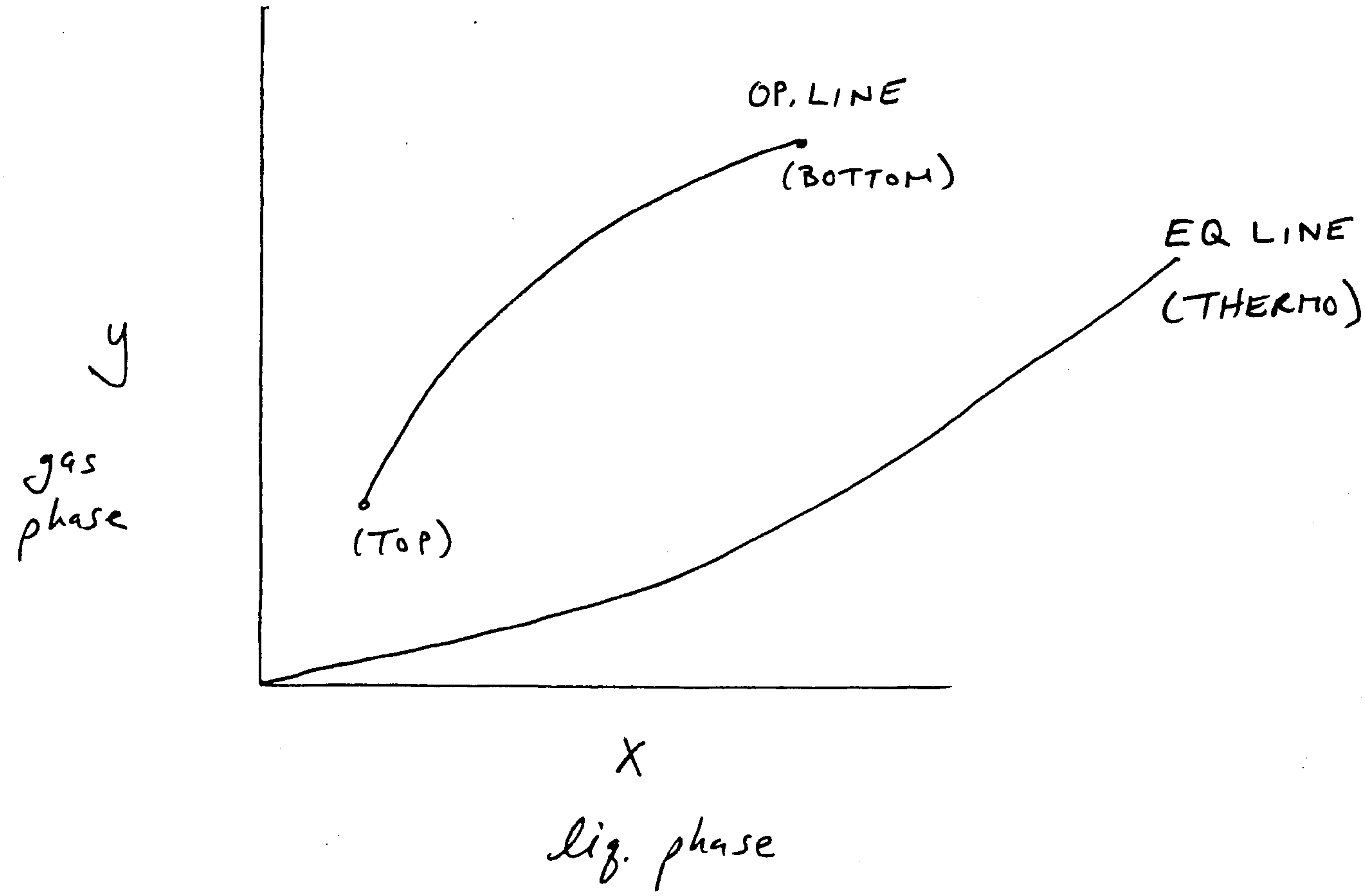
Solve for y:

$$\boxed{y = \left(\frac{L}{V}\right) x + \left[\frac{V_a y_a - L_a x_a}{V}\right]}$$

OPERATING LINE

$$\boxed{\text{Slope Op Line} = \frac{L}{V}}$$

molar basis



NOTES:

1) BOTTOM LOCATION

INLET GAS HIGHER CONC. IN <u>SOLUTE</u>

2) TOP LOCATION

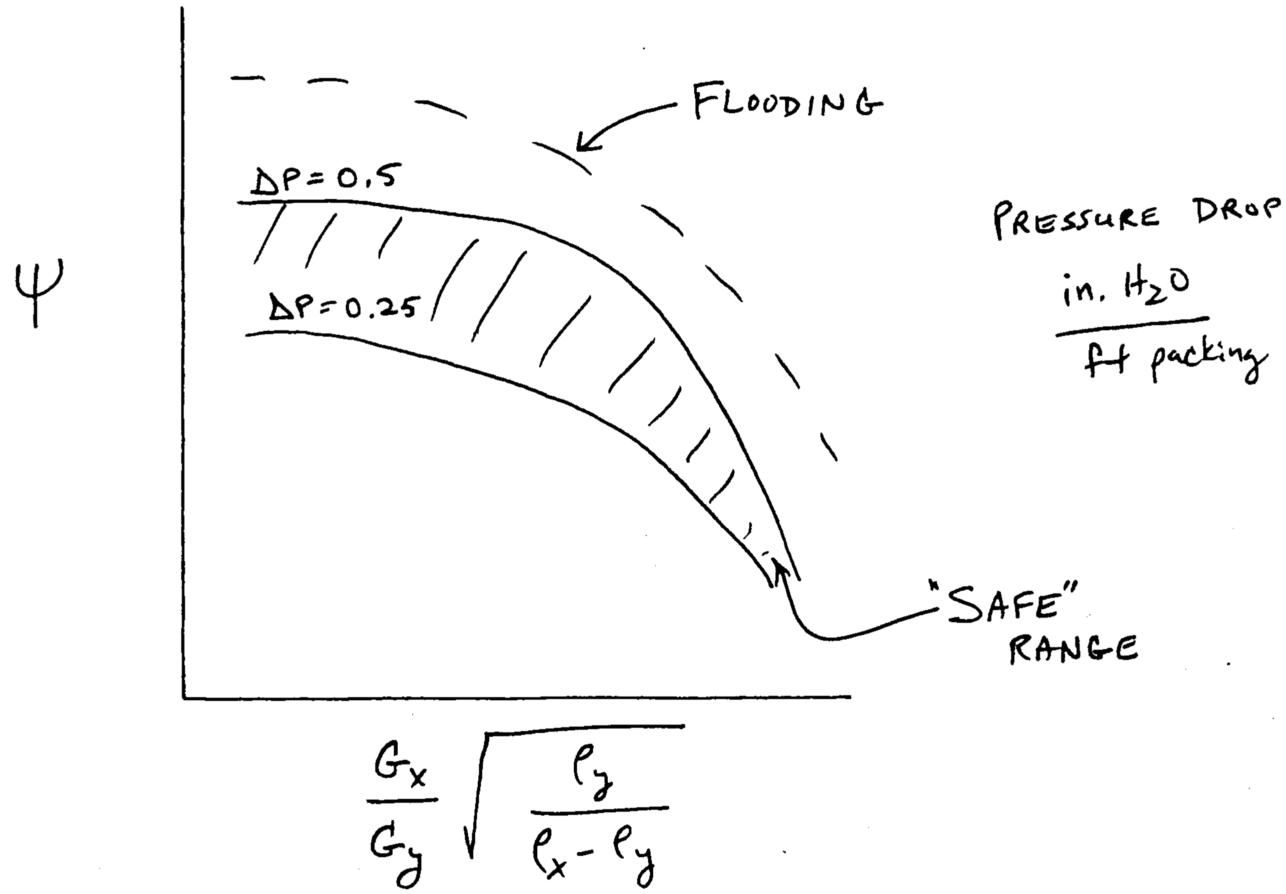
OUTLET GAS HAS LESS SOLUTE

3) OP. LINE ABOVE EQ. LINE

SOLUTE CONC. IN GAS PHASE GREATER THAN EQ $\Rightarrow$ MASS TRANSFER FROM GAS $\rightarrow$ LIQUID.

[redacted]

FLOODING CALCULATION:



$\Psi = f$ (GAS FLUX, PACKING, GAS/LIQ. PROPERTIES)

$$\Psi = \frac{G_y^2 F_p \mu_x^{0.1}}{g_c(\rho_x - \rho_y)\rho_y} \cong 0.007\, G_y^2 F_p$$

for air/H_2O @ 1atm 20°C

G_y $[=] \frac{\text{lbs}}{\text{ft}^2 \cdot \text{s}}$

F_p: packing factor (f(type/size of packing))

$$\frac{G_x}{G_y}\sqrt{\frac{\rho_y}{\rho_x - \rho_y}} \cong 0.034\left(\frac{G_x}{G_y}\right) \cong 0.021\left(\frac{L}{V}\right)$$

for air/H_2O @ 1atm 20°C

mass fluxes   molar

MATERIAL BALANCE ⇒ HEIGHT

FLOODING CALCULATION ⇒ DIAMETER

GETTING STARTED . . .

Typical Knowns:

(1) GAS FLOW IN (V or G_y)

(2) GAS COMPOSITION IN (y_b)

(3) FRACTION SOLUTE REMOVED

(Allows calculation of y_a)

(4) LIQ. COMPOSITION IN (X_a)

(5) EQ. DATA

(6) MASS TRANSFER COEFFICIENT DATA.

$$\left(k_y,\ k_x,\ K_y,\ K_x,\ \underbrace{k_y a,\ k_x a,\ K_y a,\ K_x a}_{\text{use these when area unknown}} \right)$$

Typical Unknowns:

(1) LIQ. FLOW RATE (L or G_x)

(2) COMPOSITION OF LIQUID OUT (x_b)

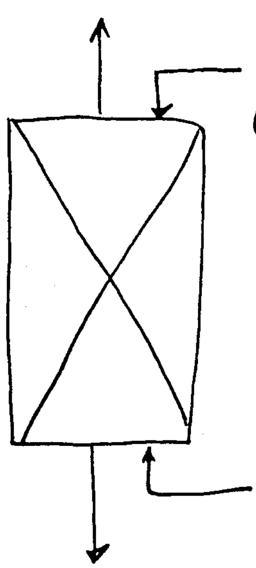
(3) ΔP IN COLUMN (FLOODING)

(4) KIND OF PACKING

(5) COLUMN CROSS-SECTIONAL AREA

(6) COLUMN HEIGHT.

EXAMPLE: COLUMN DIAMETER + ΔP



H_2O
(0% NH_3)

$25{,}000 \frac{ft^3}{hr}$ inlet gas

2% NH_3 by volume

PACKING:

1" Intalox SADDLES.

$T = 20°C$ (68°F) $P = 1$ atm

$$\frac{G_x}{(G_y)_{flood}} = 1 \frac{\text{lb liq}}{\text{lb gas}}$$

(a) if $G_y = \frac{1}{2}(G_y)_{flood}$ ⑥

$D_{TOWER} = ?$

As with most of these things, use correlated data:

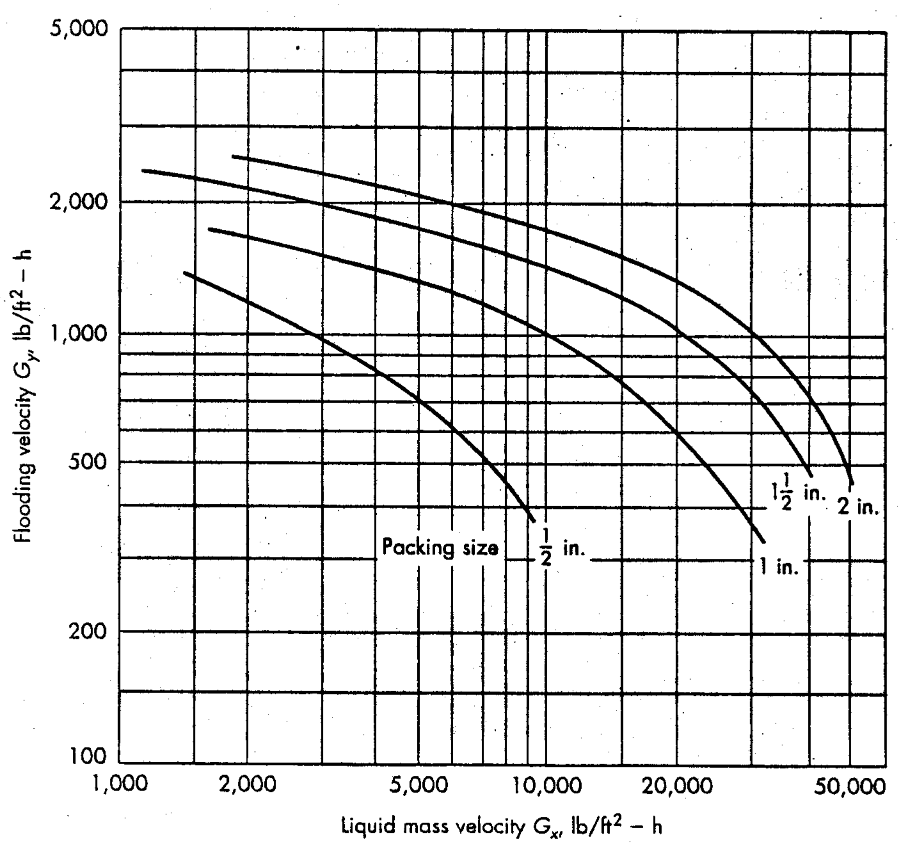


FIGURE 18.5
Flooding velocities in ceramic Intalox saddles, air-water system. (1,000 lb/ft²·h = 1.356 kg/m²·s)

Remember, $\frac{G_x}{(G_y)_{flood}} = 1$ ⇒ So, for 1" saddles

$G_x = (G_y) \cong 1700 \frac{lb}{ft^2 \cdot hr}$

Our $G_y = \frac{1}{2}(G_y)_{flood} = \frac{850 \text{ lb}}{ft^2 \cdot hr}$

Total Gas flow $= 25{,}000 \frac{ft^3}{hr}$

Convert to lbs. $\Rightarrow \rho_y$

Avg. MW of gas $= \underbrace{(29)(0.98)}_{\text{air}} + \underbrace{(17)(0.02)}_{\text{acetone}} = 28.76$

$$\rho = \underset{\substack{\uparrow \\ MW}}{(28.76)} \frac{P}{\underset{\substack{\uparrow \\ \frac{\text{moles}}{\text{volumes}}}}{RT}} = \frac{(28.76)\,lbs}{lbmol} \frac{(1 atm)(lbmol \cdot {}^\circ R)}{(0.7302\ ft^3 \cdot atm)} \left| \frac{1}{(68+460)^\circ R} \right. = 0.0746 \frac{lb}{ft^3}$$

$$\Rightarrow 25{,}000 \frac{ft^3}{hr} \left| \frac{0.0746\, lb}{ft^3} \right| = 1864.9 \frac{lb}{hr}$$

$$\text{Cross-sectional area} = 1864.9 \frac{lb}{hr} \left| \frac{ft^2 \cdot hr}{850\ lb} \right. = 2.19\, ft^2$$

$\Rightarrow$ Here, get for empty column.

$$\Rightarrow \quad 2.19\,ft^2 = \frac{\pi D_{TOWER}^2}{4}$$

$$\Rightarrow \quad \boxed{D_{TOWER} = 1.67\ ft}$$

<u>NOTE:</u> WE USED 1" Intalox Saddles.

For Column design

$$\frac{D_{packing}}{D_{TOWER}} \leq 0.1$$

$$\text{Here} = \frac{1\ in}{20.04\ in} = 0.05 \qquad (< 0.1)$$

Why? <u>Prevent channeling.</u>

b) Pressure Drop?

$\longrightarrow$

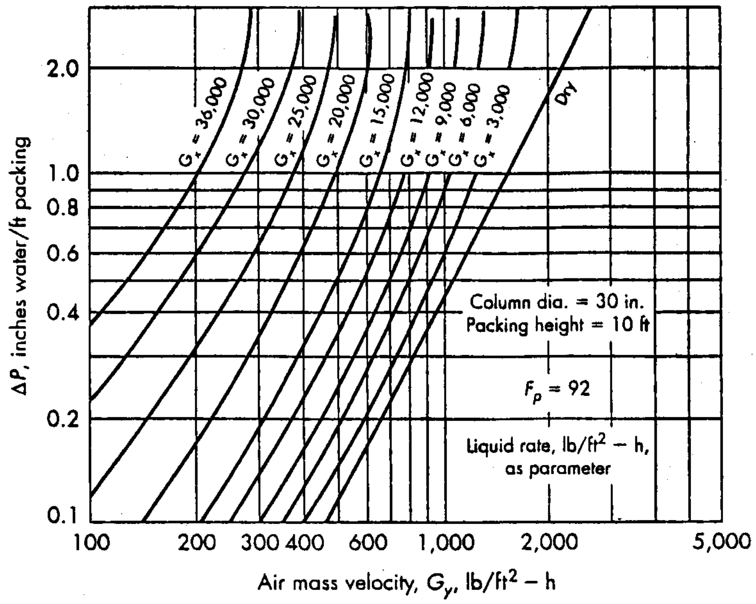


FIGURE 18.4
Pressure drop in a packed tower for air-water system with 1-in. Intalox saddles. (1,000 lb/ft^2·h = 1.356 kg/m^2·s; 1 in. H_2O/ft = 817 Pa/m)

$G_x = G_y = 850 \; \frac{lb}{ft^2 \cdot hr}$ $\Rightarrow$ $\Delta P = 0.35 \; in \; \frac{H_2O}{ft}$

in our comfort zone

if column is 20 ft high, $\Rightarrow$ $\Delta P = 7 \; in \; H_2O$

$\Rightarrow$ $\underline{\underline{0.23 \; atm}}$

NOT INSIGNIFICANT

$\Rightarrow$ CHOOSE YOUR PACKING WISELY

COLUMN HEIGHT: (Z_T)

→ CAN BE DETERMINED FROM LIQ. OR GAS PHASE

$$\boxed{Z_T = H_{oy} N_{oy} = H_{ox} N_{ox}}$$

OVERALL GAS:

$$H_{oy} = \frac{V/S}{K_y a}$$

Height of transfer unit based on overall gas mass transfer coefficient

$$N_{oy} = \int \frac{dy}{y - y^*}$$

Complimentary # of stages

OVERALL LIQUID:

$$H_{ox} = \frac{L/S}{K_x a}$$

Height of transfer unit based on overall Liq. mass transfer coefficient

$$N_{ox} = \int \frac{dx}{x^* - x}$$

Complimentary # of stages

V = molar gas flow rate [=] $\frac{\text{mol}}{\text{time}}$

S = cross-sectional area [=] length^2

L = molar liq. flow rate [=] $\frac{\text{mol}}{\text{time}}$

$K_y a$ = Overall gas phase mass transfer coefficient

[=] time^{-1}

$K_x a$ = Overall Liq. phase mass transfer coefficient

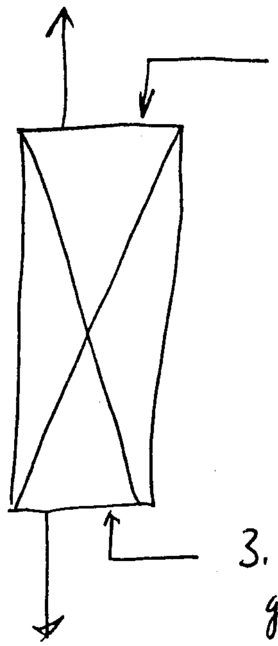
[=] time^{-1}

Z_T = Tower height [=] length

NOTE: CAN GET $K_y a$ + $K_x a$ from individual mass transfer coefficients.

(see mass transfer notes)

EXAMPLE: TOWER HEIGHT



99% Removal of A

25°C
1 atm

GAS Flux = $\dfrac{20 \text{ mol}}{\text{hr} \cdot \text{ft}^2}$

LIQ. Flux = $\dfrac{100 \text{ mol}}{\text{hr} \cdot \text{ft}^2}$

EQ. DATA: $y^* = 3.1\,X$ @ 25°C

$k_x a = 60 \text{ mol} / \text{hr} \cdot \text{ft}^3 \cdot \text{unit mol fraction}$

$k_y a = 15 \dfrac{\text{mol}}{\text{hr} \cdot \text{ft}^3 \cdot \text{unit mol fraction}}$

(a) FIND N_{oy}, H_{oy} + Z_T

ASSUMPTIONS: Isothermal

No change in Gas/Liq. Flow rates

Op. Line has constant slope

($\Rightarrow$ ~~a~~ straight line)

$X_a = ?$ Assume clean water $\Rightarrow X_a = 0$

$$X_b = \frac{\text{moles A added} \leftarrow \text{fraction A removed}}{\text{moles total}} = \frac{(20)(0.03)(0.99)}{100}$$

moles total ← assumed constant

$X_b = 0.00594$

EQ. Line: $y_b^* = (3.1)(0.00594) = 0.01841$

DRIVING FORCE: NOT LINEAR $\Rightarrow$ LOG MEAN

(SIMILAR TO HEAT TRANSFER)

@ Top: $y_a - y_a^* = \dfrac{(20)(0.03)(0.01)}{20} - 0 = 0.0003$

@ bottom: $y_b - y_b^* = 0.03 - 0.01841$

$= 0.01159$

$$\overline{\Delta y_L} = \frac{(y_b - y_b^*) - (y_a - y_a^*)}{\ln\left(\frac{y_b - y_b^*}{y_a - y_a^*}\right)} = 0.00309$$

$$N_{oy} = \int \frac{dy}{y - y^*}$$

$\overline{\Delta y_L}$ lets us substitute a constant for $y - y^*$

$$N_{oy} = \int \frac{dy}{\overline{\Delta y_L}} = \frac{1}{\overline{\Delta y_L}} \int dy = \frac{\Delta y}{\overline{\Delta y_L}}$$

$$N_{oy} = \frac{0.03 - 0.0003}{0.00309} = \underline{\underline{9.61}}$$

fractional stage

N_{oy} ok for <u>packed</u> column.

Next, H_{oy} ... but need $K_y a$

$$\frac{1}{K_y a} = \frac{1}{k_y a} + \frac{M}{k_x a}$$

Slope EQ Line

$$\frac{1}{K_y a} = \frac{1}{15} + \frac{3.1}{60} = 0.11833$$

$$\Rightarrow K_y a = 8.45$$

$$H_{oy} = \left(\frac{20\ \text{mol}}{ft^2 \cdot hr}\right)\left(\frac{1\ ft^3 \cdot hr}{8.45\ \text{mol}}\right) = \underline{\underline{2.37\ ft.}}$$

H_{oy}

$$\boxed{Z_T = (9.61)(2.37) = 22.7\ ft}$$

Similar analysis for liq. phase.

NOTE: $H_{o} \neq H_{ox}$ $N_{ox} \neq N_{oy}$ but $H_{oy} N_{oy} = H_{ox} N_{ox}$