EXAMPLE 10 (in class) 12 April 2019 FAM CM3120 (1)

Example: Height of a packed bed absorber

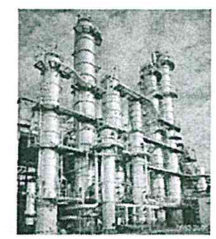
How can we use the linear driving force model for mass transfer to design a packed bed gas absorber to achieve a desired separation?

From lecture 8:

How should we model?

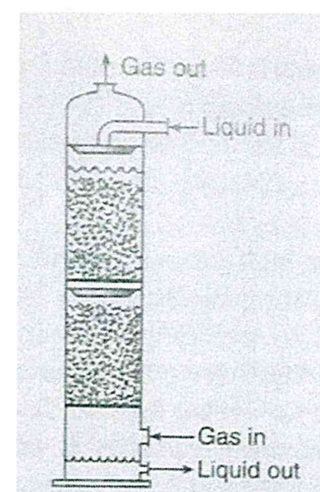
What should we pick for the C.V.?

Gas Absorption



While a chemical plant would not exist without the chemical reactors, the biggest expense (the biggest equipment) will often be the separation equipment, **distillation columns** and **gas absorption columns**.

- Packed column (tower)
- Liquid poured into top trickles down through packing
- Gas pumped into bottom flows upward
- Analysis involves both **fluid mechanics** (determines cross-sectional area) and **mass transfer** (determines height)



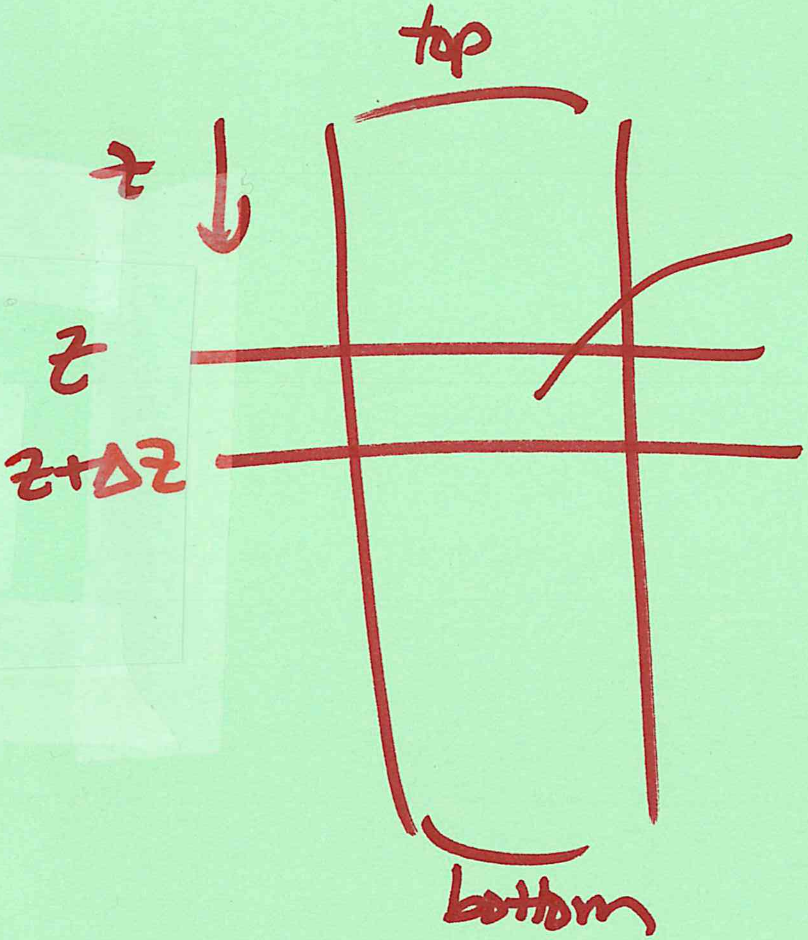
We are concerned w/ mass xfer, ∴ :

SOURCE → SINK

GAS (source) → LIQUID (sink)

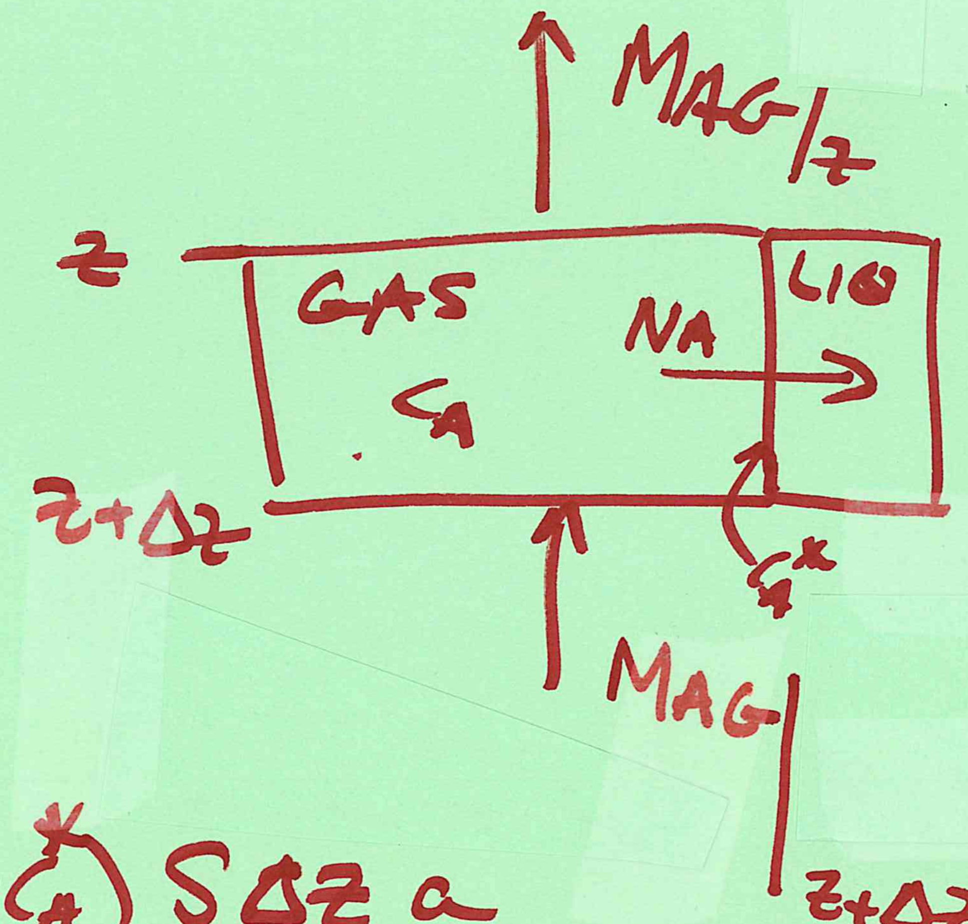
- choose slice (pseudo SS soln) of column
- choose gas phase in the slice as c.v.

(could pick liquid: choice is arbitrary)



GAS in this slice is the chosen c.v.

volume: $\Delta z S$



flux A out of c.v.

$$\underbrace{N_A}_{} = k_c \left(C_A - C_A^*\right) \underbrace{S \Delta z\, a}_{\text{surface area for mass xfer}}$$

MOLES

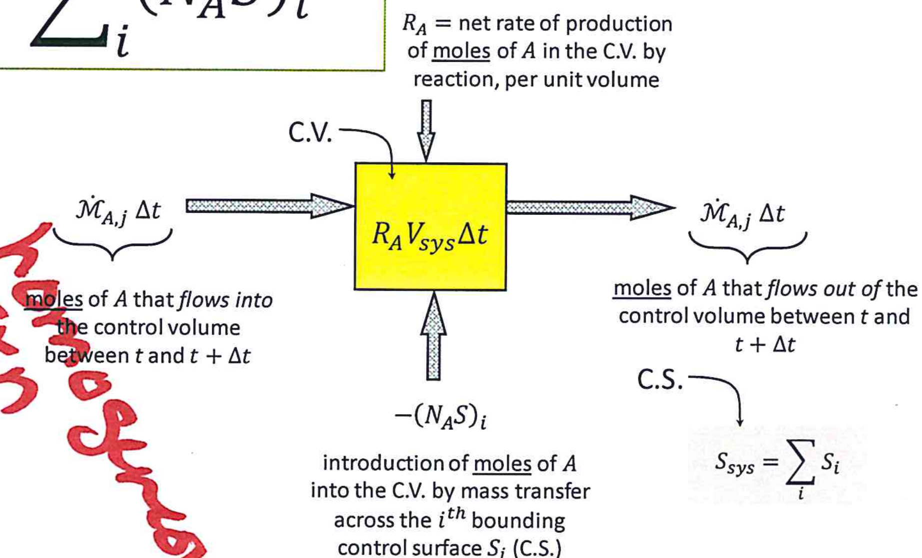
(4)

accumulation = net flow in + production + introduction

$$\frac{d}{dt}\left(\mathcal{M}_{A,sys}\right) = -\Delta\dot{\mathcal{M}}_A + R_A V_{sys} - \sum_i (N_A S)_i$$

pseudo ss

no homogeneous rxn



$\mathcal{M}_{A,sys} = c_A V_{sys}$ = total moles of A in the C.V.

$\Delta\dot{\mathcal{M}}_A = \sum_{j,outs} \dot{\mathcal{M}}_{A,j} - \sum_{j,ins} \dot{\mathcal{M}}_{A,j}$

R_A = net rate of production of moles of A in the C.V. by reaction, per unit volume

V_{sys} = system volume

N_{A_i} = molar flux of A out through the i^{th} C.S.

$S_{sys} = \sum_i S_i$

Δ is "out"- "in"

C.S. = control surface

C.V. = control volume

$a = \frac{\text{area for mass xfer}}{\text{volume of packing}}$

macro species A mass bal (pseudo SS)

$$0 = -\left(\overbrace{M_{AG}\Big|_{z}}^{\text{out}} - \overbrace{M_{AG}\Big|_{z+\Delta z}}^{\text{in}}\right)$$

$$- \left(\overbrace{k_c(C_A - C_A^*)}^{\text{flux out}} S \Delta z\, a\right)$$

$k_c(C_A - C_A^*)$ → $k_y a (y_A - y_A^*)$ to follow convention switch to k_y

$$\lim_{\Delta z \to 0} \frac{M_{AG}\Big|_{z+\Delta z} - M_{AG}\Big|_{z}}{\Delta z}$$

$$= \frac{dM_{AG}}{dz}$$

$$0 = \frac{dM_{AG}}{dz} - (k_y a)(y_A - y_A^*) S$$

$$\frac{dM_{AG}}{dz} = (k_y a) S (y_A - y_A^*)$$

by convention, use "molar ratios" instead of mole fraction. Also, assume dilute A systems.

$$Y_A = \frac{\text{mole A}}{\text{mole I}} \approx y_A \text{ (dilute)}$$

$$M_{AG} = M_G Y_A$$

$$\frac{\text{mole I}}{} \quad \frac{\text{mole A}}{\text{mole I}}$$

$\Rightarrow$

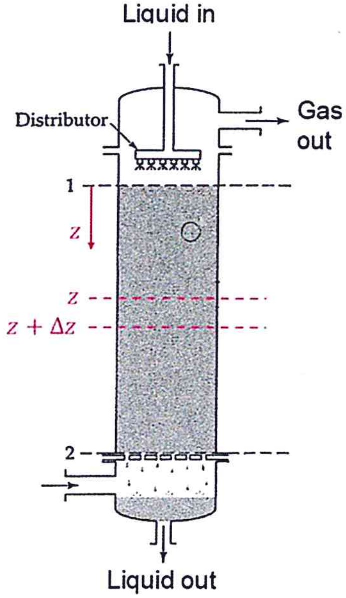
$$M_G \frac{d\bar{y}_A}{dz} = S(k_g a)(\bar{y}_A - y_A^*)$$

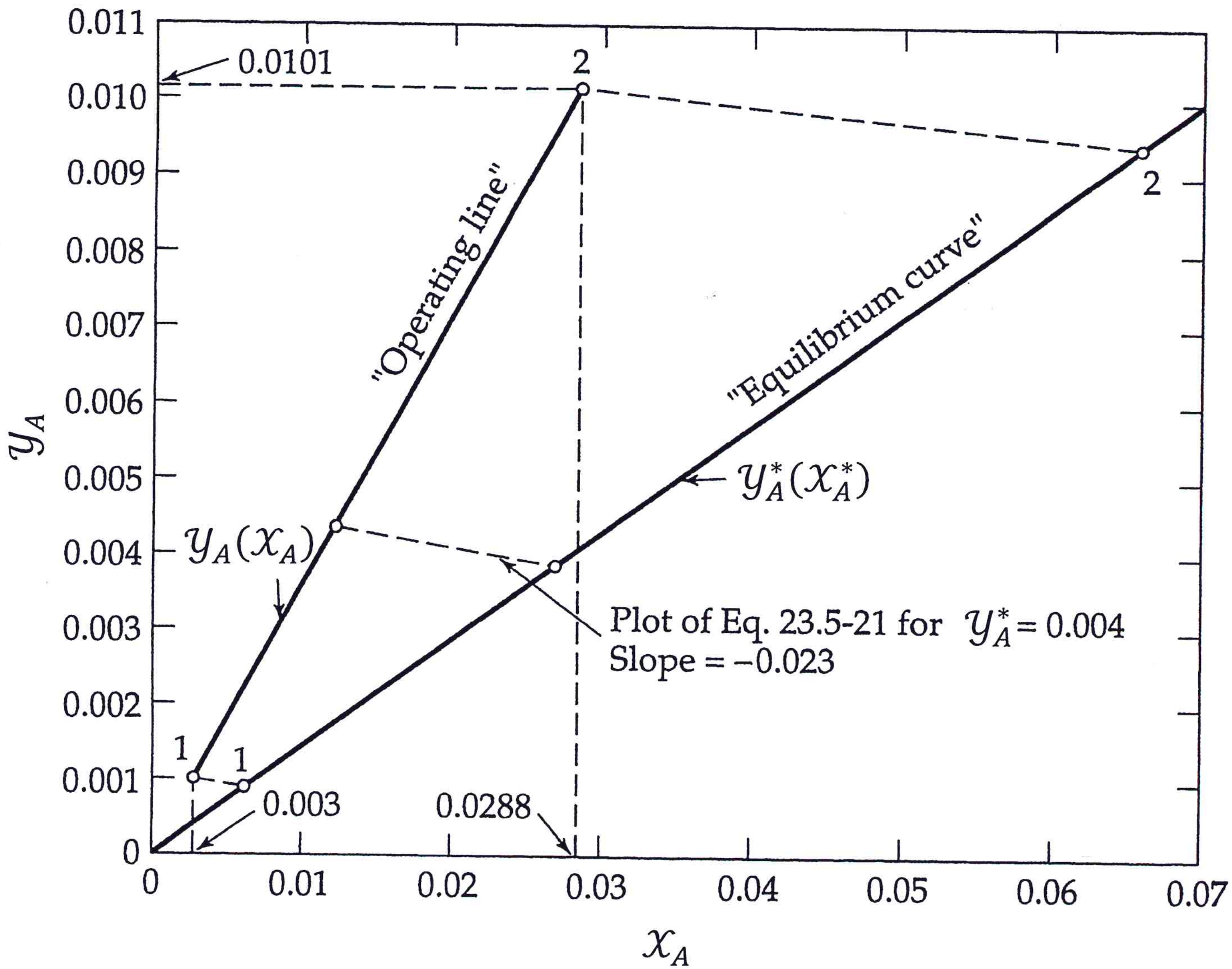
$$\int_{y_{A_1}}^{y_{A_2}} \frac{d\bar{y}_A}{\bar{y}_A - y_A^*} = \int_0^L \frac{(k_g a) S}{M_G} dz = \frac{(k_g a) L S}{M_G}$$

y_A^* is NOT constant!

$\Rightarrow$ numerical integration

Unsteady Macroscopic Species A Mass Balance—Gas Absorption

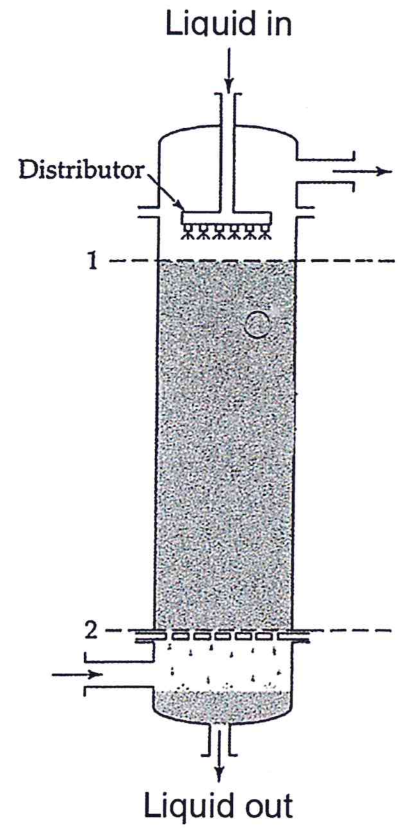




BSL2 p745 Bird, Stewart, and Lightfoot, Transport Phenomena, 2[nd] ed., Wiley, 2006.

Solution:

(height of a packed bed absorber)



Answer: Perform numerical integration to obtain the column height L:

$$L = \frac{\mathcal{M}_G}{(k_y a) S} \int_{y_{A1}}^{y_{A2}} \frac{d y_A}{(y_A - y_A^*)}$$

Need: Gas flow rate $\mathcal{M}_G$, column cross sectional area S, data on thermodynamic equilibrium $y_A^*(x_A^*)$, desired separation (mole fractions top and bottom, and mass transfer coefficients $k_y a$ and $k_x a$.