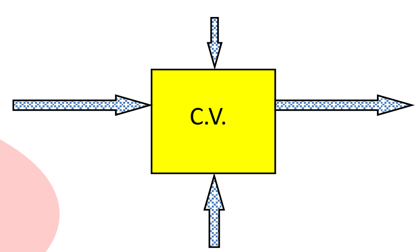
CM3120: Module 4

Diffusion and Mass Transfer II

I. Classic diffusion and mass transfer: d) EMCD
II. Classic diffusion and mass transfer: e) Penetration model
III. Unsteady macroscopic species A mass balances (Intro)
IV. Interphase species A mass transfers—To an interface—k_x, k_c, k_p
V. Unsteady macroscopic species A mass balances (Redux)
VI. Interphase species A mass transfers—Across multiple resistances—K_L, K_G
VII. Dimensional analysis
VIII. Data correlations

1

CM3120: Module 4



Module 4 Lecture III

Unsteady Macroscopic species A mass balances

(Introduction)

Professor Faith A. Morrison

Department of Chemical Engineering
Michigan Technological University

www.chem.mtu.edu/~fmorriso/cm3120/cm3120.html

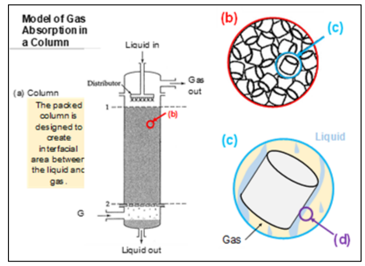
2

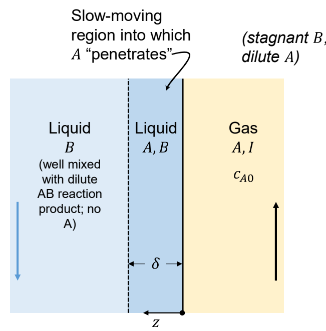
Unsteady Macroscopic Species A Mass Balance—Intro

In lecture II we developed a picture of how the mass moves around in an absorber (**penetration model**).

How can we design a packed bed gas absorber to achieve a desired separation?

In momentum and heat transfer we often sorted out "devices" with a macroscopic balance. Shall we try this?





Unsteady Macroscopic Species A Mass Balance

Example 6

A practical problem

Example 6: Height of a packed bed absorber

How can we use mass transfer to design a packed bed gas absorber to achieve a desired separation?

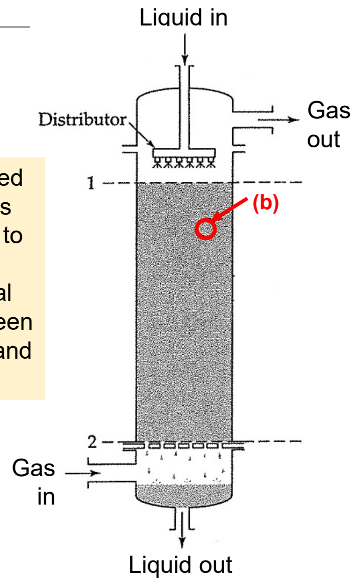
BSL2 p742

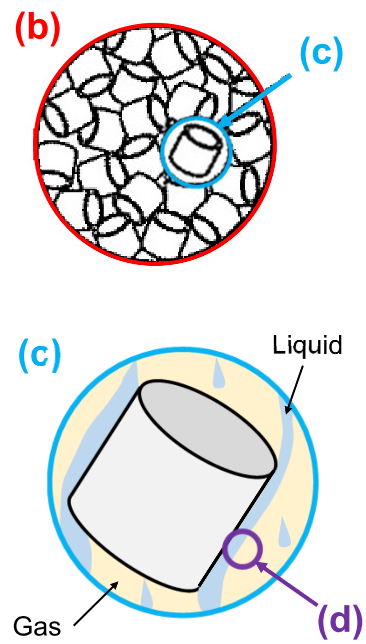
From earlier lecture:

Model of Gas Absorption in a Column

(a) Column

The packed column is designed to create interfacial area between the liquid and gas.





BSL2, p743

1D Steady Diffusion—Gas Absorption with Chemical Solvent

From earlier lecture:

The Mass-Transfer Model

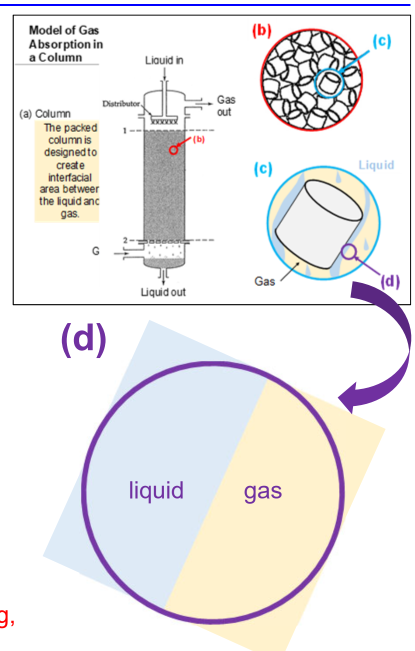
We focus on the **liquid-gas interface** where the mass transfer takes place.

Idealize the **entire device** as comprising only the appropriate amount of this interface, with mass transfer taking place there.

Retain the role of the column, by forcing the appropriate concentrations of species A to enter and exit the column.

$$a \equiv \frac{\text{interfacial area}}{\text{volume}}$$

A property of the column and packing, in operation



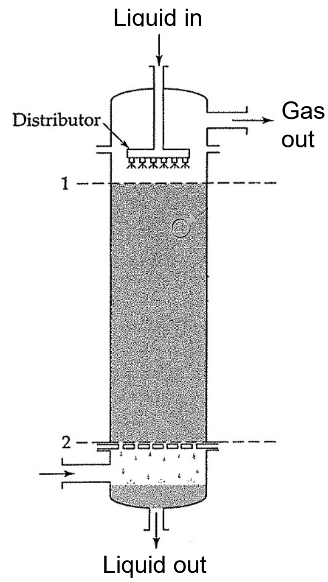
Unsteady Macroscopic Species A Mass Balance—Intro

Example 6

What is our model for the entire column??

(our assumptions)

1. Control volume =
2.



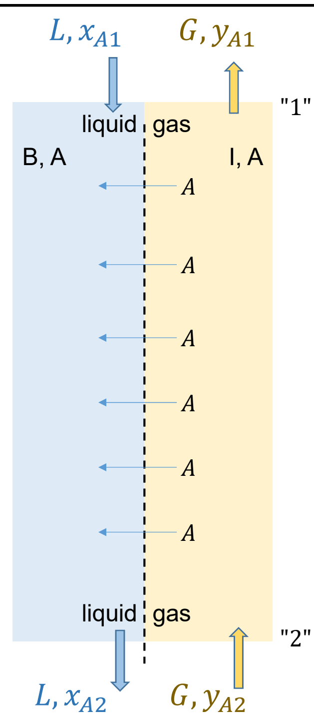
7

Model of Gas Absorption in a Column

top of column

Liquid B attracts A; the concentration of A increases as the liquid passes through the column

The preference of species A for liquid B rather than inert gas I is due to a difference in *chemical potential*

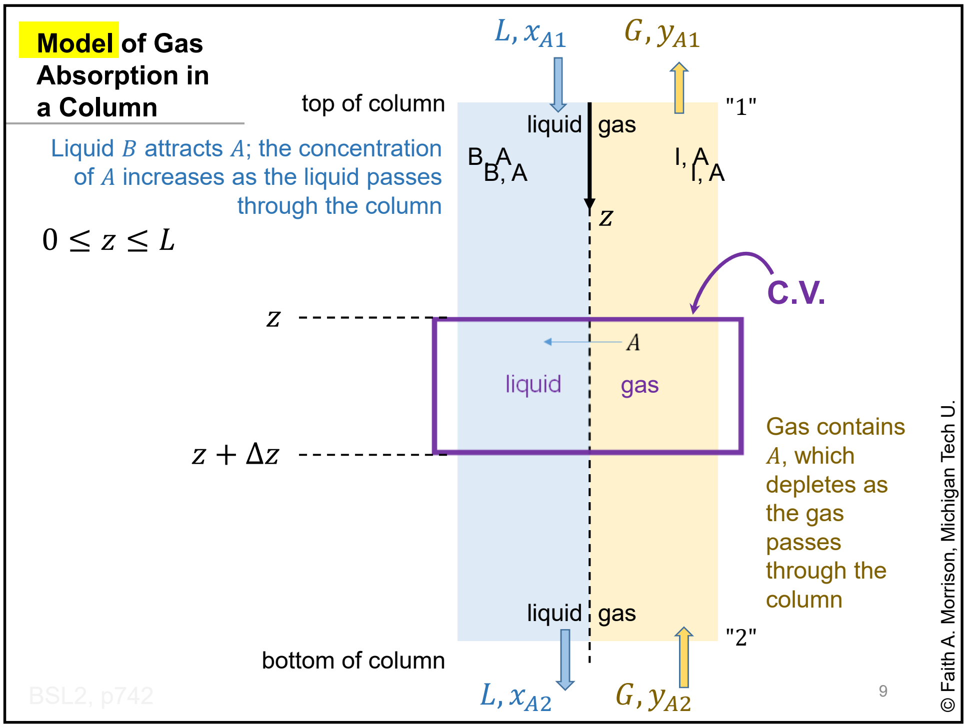


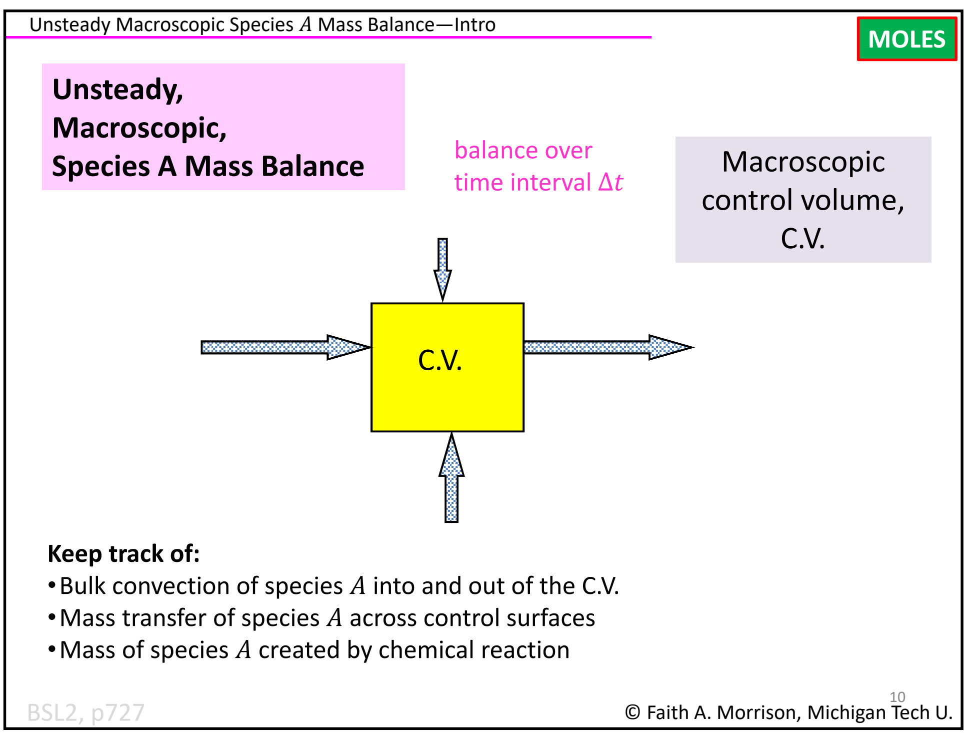
bottom of column

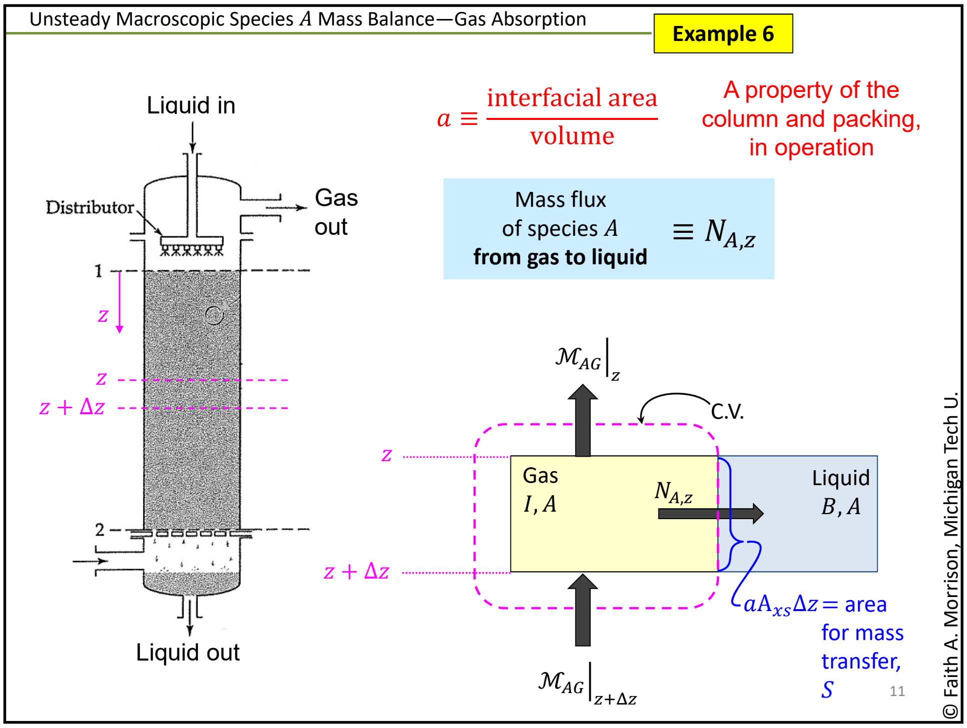
Gas contains A, which depletes as the gas passes through the column

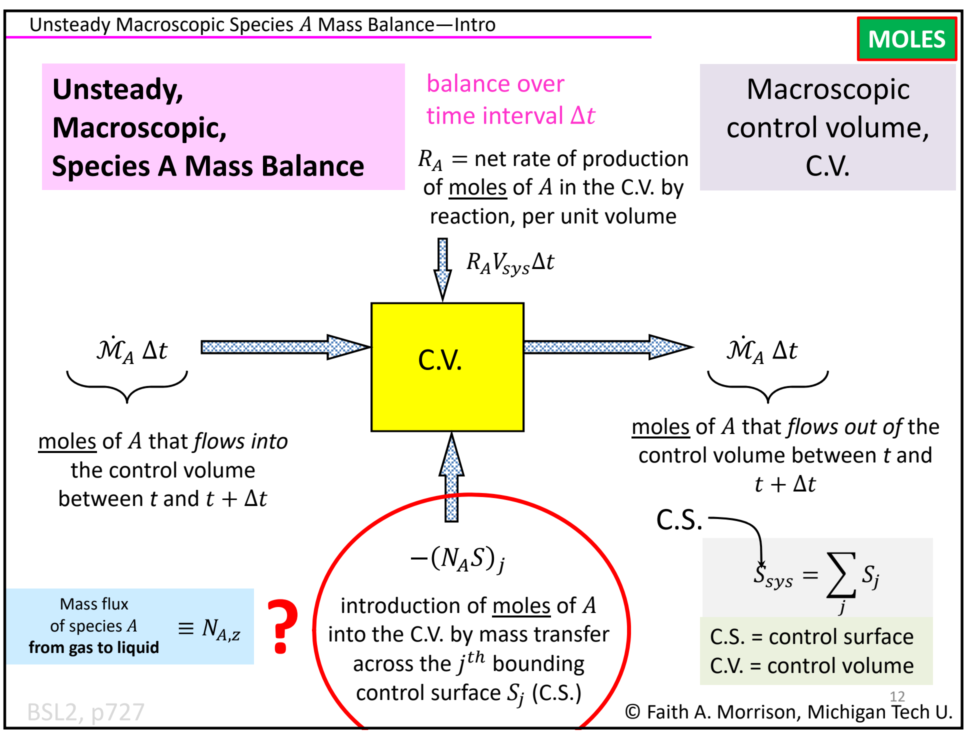
BSL2, p742

8


Model of Gas Absorption in a Column
Liquid B attracts A; the concentration of A increases as the liquid passes through the column
$0 \leq z \leq L$
top of column
L, x_{A1}
G, y_{A1}
"1"
liquid
gas
B, A
I, A
z
C.V.
z
A
liquid
gas
$z + \Delta z$
Gas contains A, which depletes as the gas passes through the column
liquid
gas
"2"
bottom of column
L, x_{A2}
G, y_{A2}
BSL2, p742
9
© Faith A. Morrison, Michigan Tech U.


Unsteady Macroscopic Species A Mass Balance—Intro
MOLES
Unsteady, Macroscopic, Species A Mass Balance
balance over time interval Δt
Macroscopic control volume, C.V.
C.V.
Keep track of:
•Bulk convection of species A into and out of the C.V.
•Mass transfer of species A across control surfaces
•Mass of species A created by chemical reaction
BSL2, p727
10
© Faith A. Morrison, Michigan Tech U.


Unsteady Macroscopic Species A Mass Balance—Gas Absorption
Example 6
$a \equiv \frac{\text{interfacial area}}{\text{volume}}$
A property of the column and packing, in operation
Mass flux of species A from gas to liquid $\equiv N_{A,z}$
Liquid in
Distributor
Gas out
1
z
z
$z + \Delta z$
2
Liquid out
$\mathcal{M}_{AG}\big|_z$
C.V.
z
Gas
I, A
$N_{A,z}$
Liquid
B, A
$z + \Delta z$
$aA_{xs}\Delta z =$ area for mass transfer, S
$\mathcal{M}_{AG}\big|_{z+\Delta z}$
11
© Faith A. Morrison, Michigan Tech U.

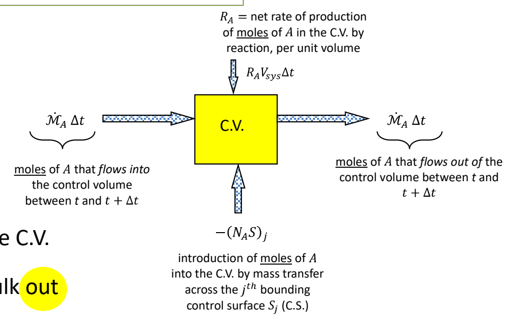

Unsteady Macroscopic Species A Mass Balance—Intro
MOLES
Unsteady, Macroscopic, Species A Mass Balance
balance over time interval Δt
R_A = net rate of production of moles of A in the C.V. by reaction, per unit volume
Macroscopic control volume, C.V.
$R_A V_{sys} \Delta t$
$\dot{\mathcal{M}}_A \, \Delta t$
moles of A that flows into the control volume between t and $t + \Delta t$
C.V.
$\dot{\mathcal{M}}_A \, \Delta t$
moles of A that flows out of the control volume between t and $t + \Delta t$
C.S.
$S_{sys} = \sum_j S_j$
$-(N_A S)_j$
introduction of moles of A into the C.V. by mass transfer across the j^{th} bounding control surface S_j (C.S.)
Mass flux of species A from gas to liquid $\equiv N_{A,z}$
?
C.S. = control surface
C.V. = control volume
BSL2, p727
12
© Faith A. Morrison, Michigan Tech U.

Unsteady Macroscopic Species A Mass Balance—Intro

MOLES

accumulation = net flow in + production + introduction

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



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

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

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

V_{sys} = system volume

$N_{A_j} = K\Delta c_{df}$ =molar flux of A out through the j^{th} C.S. ?

$S_{sys} = \sum_j S_j$
Δ is "out"- "in"
C.S. = control surface
C.V. = control volume

13

Unsteady Macroscopic Species A Mass Balance--Intro

MOLES

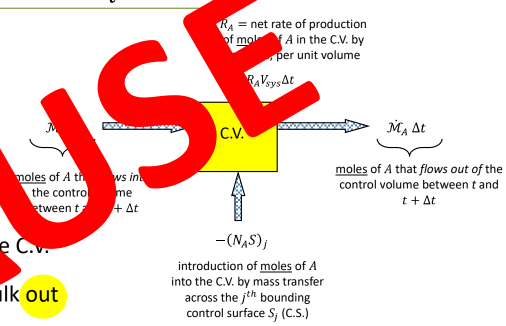
accumulation = net flow in + production + introduction

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

Need:

Mass flux of species A **from gas to liquid** $\equiv N_{A,z}$

PAUSE



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

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

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

V_{sys} = system volume

$N_{A_j} = K\Delta c_{df}$ =molar flux of A out through the j^{th} C.S. ?

$S_{sys} = \sum_j S_j$
Δ is "out"- "in"
C.S. = control surface
C.V. = control volume

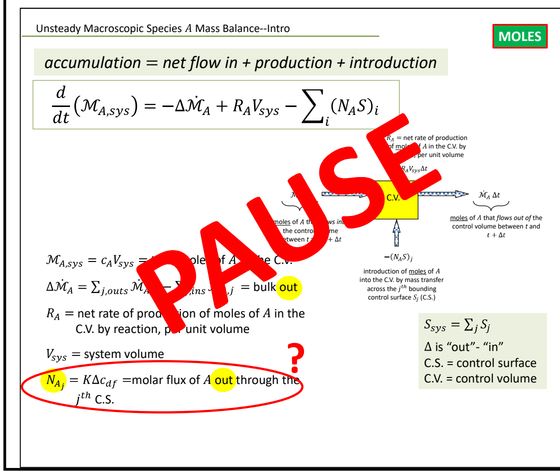
14

Unsteady Macroscopic Species A Mass Balance

Example 6

Example 6: Height of a packed bed absorber

How can we use mass transfer to design a packed bed gas absorber to achieve a desired separation?



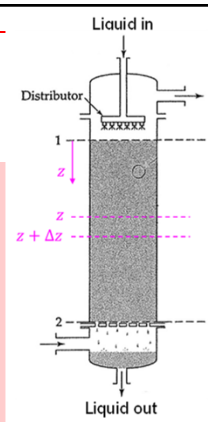
Pause: We need a way to account for **mass transfer from one phase to another** in a macroscopic control volume before this can become an effective tool.

We will return to this problem in Lecture IV.

15

Unsteady Macroscopic Species A Mass Balance--Intro

Macroscopic Species A Balances Summary (so far)



- To model entire devices, we need ***macroscopic*** control volumes
- The diffusion coefficient is **not a convenient** way to model mass transfer into a macroscopic control volume.
- In **heat transfer** we used Newton's law of cooling in the macroscopic balance as the source of convective heat flow:

$$\dot{q}_{in} = hA(T_b - T_w)$$

- Maybe someone has invented a "**mass transfer coefficient**" K analogous to the heat transfer coefficient h?

$$N_A = K\Delta c_{df}$$

Take a **PAUSE** to figure this out

16

Modeling practical devices involving mass transfer

Example 6: Height of a packed bed absorber

How can we use mass transfer to design a packed bed gas absorber to achieve a desired separation?

Example 6 is presented as a series of **linked examples** that navigate around apparent "dead ends" in modeling mass-transfer units

Identify a question	Invent something	Try to use it
1. How can we model a large, practical device dependent on mass transfer?	1. Apply the species A mass balance to a macroscopic C.V.	1. Lack a system to account for A going between phases
2. How an we account for A going between phases?	2. Invent k_x through linear driving force (LDF) model	2. Gets A *to* the boundary, but not *across*
3. How can we improve LDF model to cross the boundary (bulk-to-bulk transfer)?	3. Write LDF in both phases and combine to create overall effect of multiple resistances	3. Working, but can we devise a convenient shorthand?
4. Can we model a large, practical device, incorporating K_L, K_G to account for mass xfer between phases?	4. Yes	

Modeling practical devices involving mass transfer

Example 6: Height of a packed bed absorber

How can we use mass transfer to design a packed bed gas absorber to achieve a desired separation?

Example 6 is presented as a series of **linked examples** that navigate around apparent "dead ends" in modeling mass-transfer units

LECTURES

Identify a question	Invent something	Try to use it
✓ 1. How can we model a large, practical device dependent on mass transfer? **III**	✓ 1. Apply the species A mass balance to a macroscopic C.V. **III**	✓ 1. Lack a system to account for A going between phases **PAUSE III**
2. How an we account for A going between phases? **IV**	2. Invent k_x through linear driving force (LDF) model **IV**	2. Gets A *to* the boundary, but not *across* **PAUSE V**
3. How can we improve LDF model to cross the boundary (bulk-to-bulk transfer)? **VI**	3. Write LDF in both phases and combine to create overall effect of multiple resistances **VI**	3. Working, but can we devise a convenient shorthand? **PAUSE VI**
4. Can we model a large, practical device, incorporating K_L, K_G to account for mass xfer between phases? **VI**	4. Yes **VI**	

18