12 April 2021 CM3120 MOD 4 LECTURE VI

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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

TODAY →

LDF = Linear Driving Force model

$N_A = k \, \Delta c_{d.f.}$

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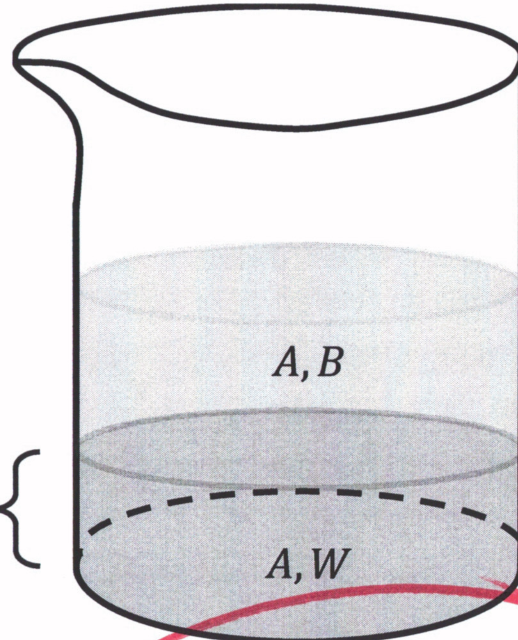
Driving Force for Mass Transfer

What is Δc_{df}?

(bulk to bulk)

$t = 0$



bromine in **benzene**

$\tilde{c}_A = \tilde{c}_{A0}$

bromine in **water**

$c_A = c_{A0}$

driving force for mass xfer

In the **A,B bromine** in **benzene phase:**

$t \geq 0$

$$N_A = K_{AB}\left(\tilde{c}_A^*(c_A) - \tilde{c}_A\right)$$

In the **A,W bromine** in **water phase:**

$t \geq 0$

$$N_A = K_{AW}\left(c_A - c_A^*(\tilde{c}_A)\right)$$

Mass transfer driving force related to distance from chemical equilibrium

Equilibrium

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What is K?

(bulk to bulk)

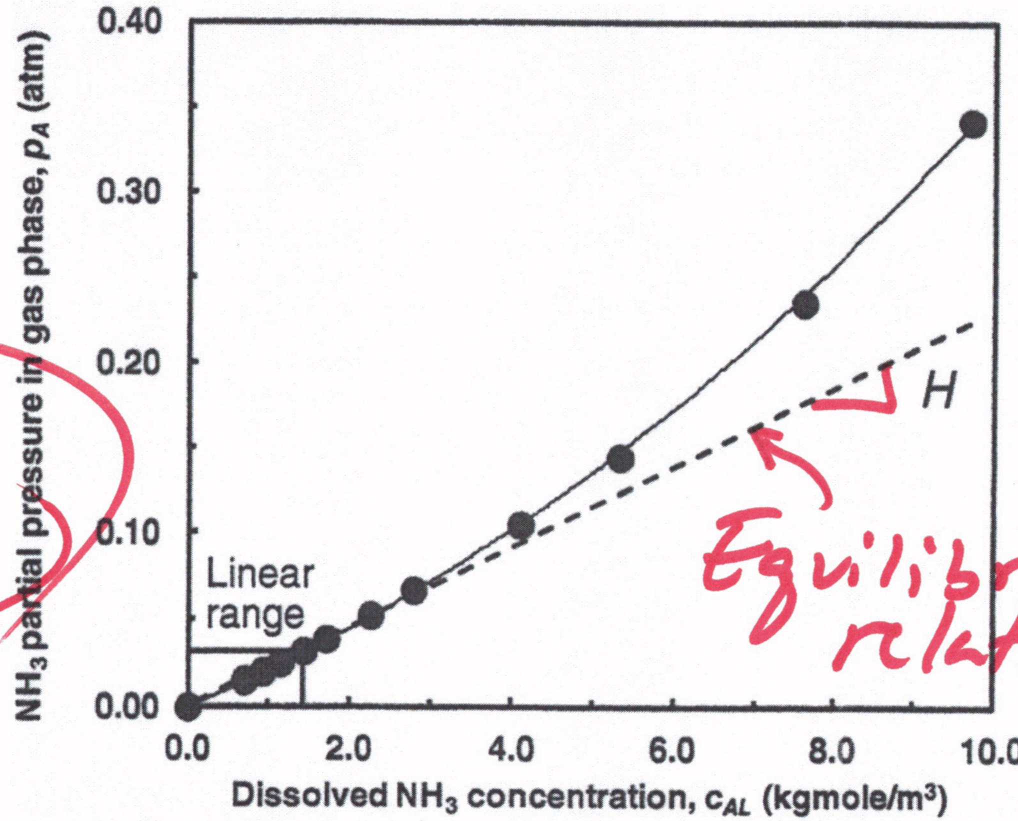
Phase Equilibrium Data (*material function*)

Phase equilibrium data are published in the literature

In the **dilute** regime, the equilibrium curve is linear (**Henry's law**):

$$p_A^* = H x_A^*$$

In the non-dilute (concentrated) concentrated regime, the equilibrium curve is not linear



WRF Ch29, Fig 29.2

Equilibrium relationship

(there is no resistance at the interface, equilibrium is established)

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What is K?

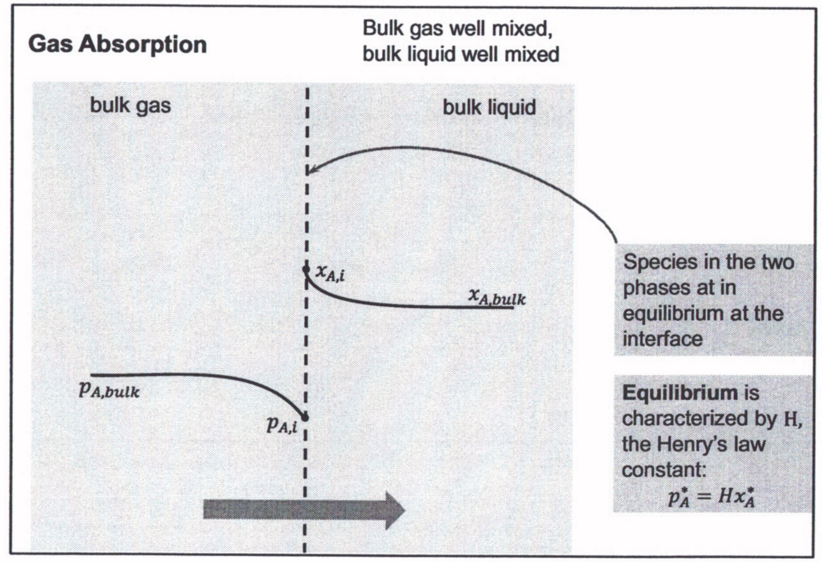
(bulk to bulk)

Example 11: What are the liquid and gas concentrations at the interface?

Equilibrium in mixtures dilute in A is characterized by H, the Henry's law constant:

$$p_A^* = Hx_A^*$$

dilute regime



Let's try

$$N_A = \underbrace{k_p(p_A - p_{Ai})}_{N_{AG}} = \underbrace{k_x\left(x_{A,i} - x_A\right)}_{N_{AL}}$$

Ex 11

$$N_{A_{LIQ}} = N_{A_{GAS}}$$

solve for

$$k_p (p_A - p_{A_i}) = k_x (x_{A_i} - x_A)$$

$$p_{A_i} = p_A^* = H x_A^* = H x_{A_i}$$

collect x_{A_i}:

$$k_p (p_A - H x_{A_i}) = k_x x_{A_i} - k_x x_A$$

$$k_p p_A + k_x x_A = x_{A_i} (k_x + k_p H)$$

$$\boxed{x_{A_i} = \frac{k_p p_A + k_x x_A}{k_x + k_p H}}$$

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Example 12: What is the flux from gas to liquid?

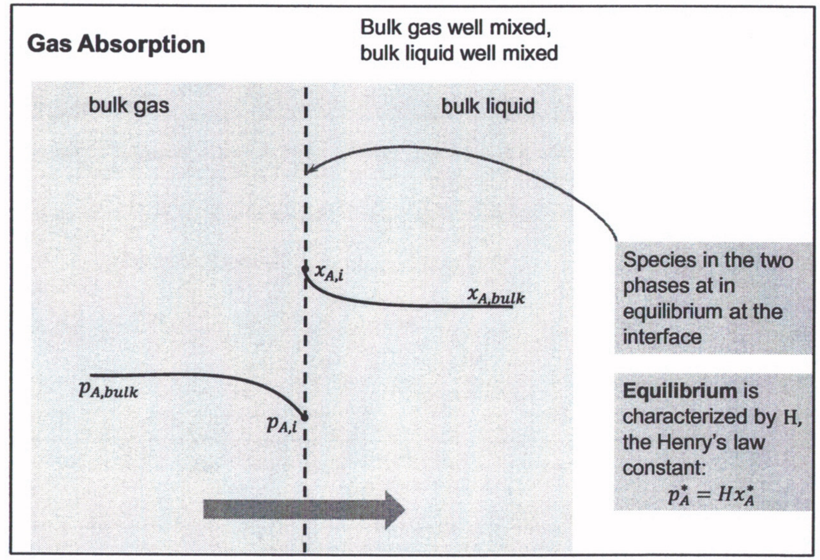
What is K?

(bulk to bulk)

Equilibrium in mixtures dilute in A is characterized by H, the Henry's law constant:

$$p_A^* = Hx_A^*$$

dilute regime



Let's try

$$N_A = k_p(p_A - p_{Ai}) = k_x(x_{A,i} - x_A)$$

use previous results to eliminate interface conditions

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EXAMPLE 12: What is NA ?

$$N_A = k_p (p_A - \underbrace{p_{Ai}}_{H x_{Ai}})$$

$$x_{Ai} = \frac{k_p p_A + k_x x_A}{k_x + H k_p}$$

$$= \cancel{k_p} \left(p_A - \frac{H k_p p_A + H k_x x_A}{k_x + H k_p} \right) \qquad \frac{\frac{1}{\cancel{k_p}}}{\frac{1}{k_p}}$$

$$= \frac{p_A \cancel{k_x} + \cancel{H k_p p_A} - \cancel{H k_p p_A} - H \cancel{k_x} x_A}{\left(\frac{k_x}{k_p} + H \right)} \qquad \frac{\frac{1}{\cancel{k_x}}}{\frac{1}{k_x}}$$

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$$\boxed{N_A = \frac{P_A - H x_A}{\frac{1}{k_p} + \frac{H}{k_x}}}$$

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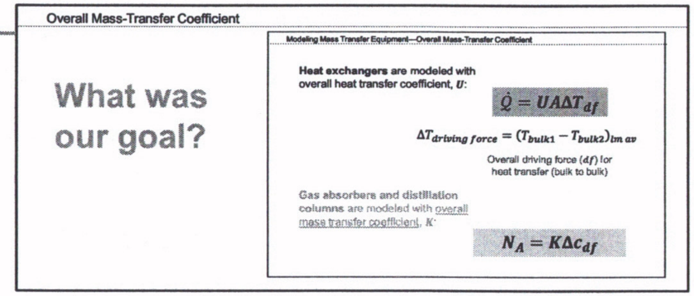


The **Overall Mass-Transfer Coefficients** *equivalently* describe the steady state relationship between the bulk concentrations (gas and liquid) of a composite scenario (slice of gas absorber)

Henry's law:

$$p_A^* = Hx_A^*$$

dilute regime

$$N_A = K_G[p_A - Hx_A]$$

$$K_G \equiv \left(\frac{1}{\frac{H}{k_x} + \frac{1}{k_p}}\right)$$

GAS

K_G is the <u>gas-side-units</u> overall mass transfer coefficient

Both include **both** resistances

$$N_A = K_L\left[\frac{p_A}{H} - x_A\right]$$

$$K_L \equiv \left(\frac{1}{\frac{1}{k_x} + \frac{1}{Hk_p}}\right)$$

LIQ

re-arrange algebraically to use LIQ side

K_L is the <u>liquid-side-units</u> overall mass transfer coefficient

Driving forces written differently, but are equivalent

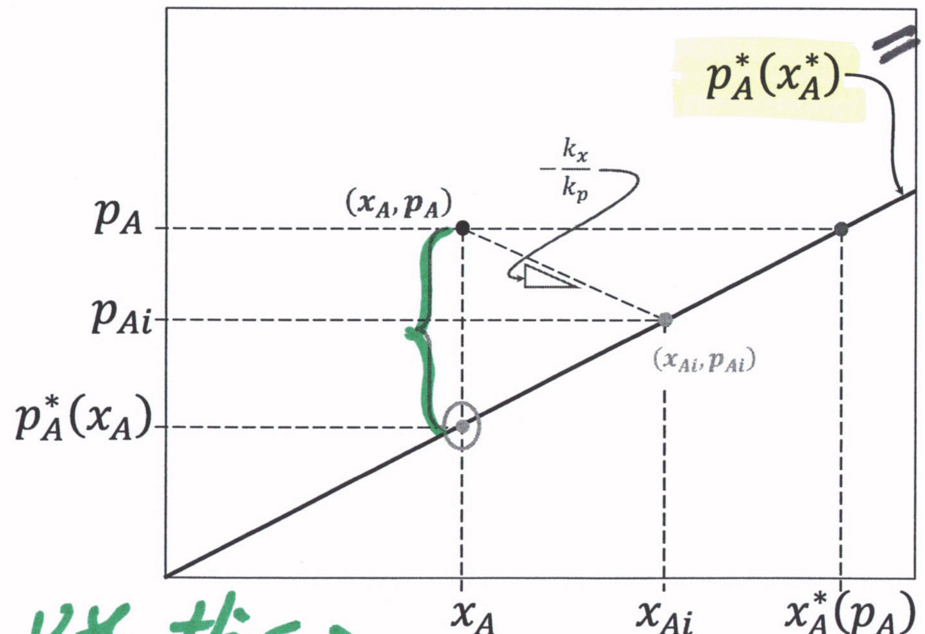
We can visualize the <u>gas-phase-units</u> **driving force** as a vertical segment:

VISUALIZE

Gas-phase-units:

<u>Overall</u> Linear driving force model:

$$N_A = K_G(\underbrace{p_A - H x_A}_{\Delta c_{df}})$$



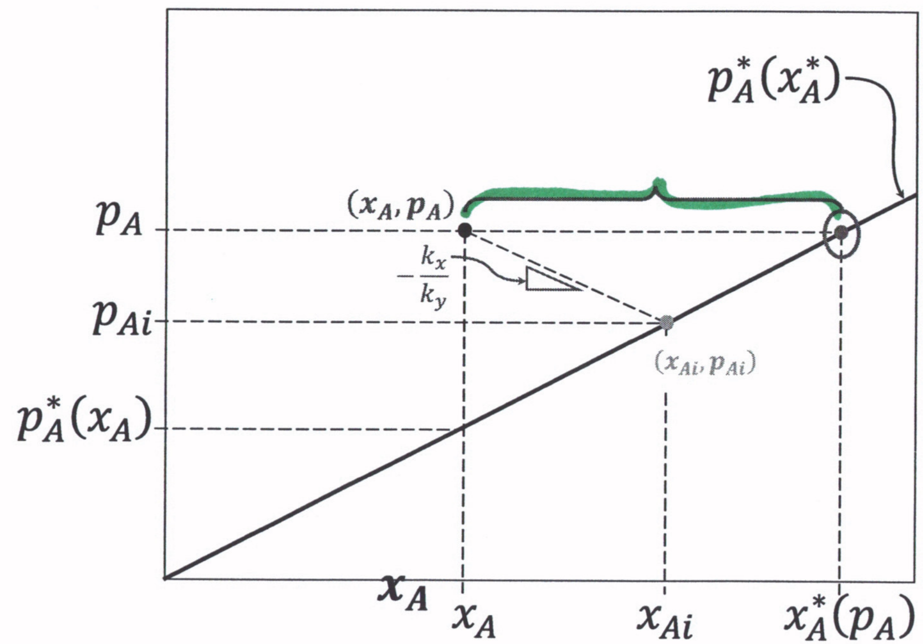
use this

It turns out: $Hx_A = p_A^*(x_A) =$ The gas partial pressure that a liquid of concentration x_A (the liquid bulk mole fraction) would be in equilibrium with

dilute regime

to define for concentrated!

We can visualize the liquid-phase-units **driving force** as a horizontal segment:



Liquid-phase-units

Overall Linear driving force model:

$$N_A = K_L \underbrace{\left(\frac{p_A}{H} - x_A\right)}_{\Delta c_{df}}$$

It turns out: $\frac{p_A}{H} = x_A^*(p_A) \equiv$ The liquid mole fraction that a gas of partial pressure p_A (the gas bulk partial pressure) would be in equilibrium with

dilute regime

use for concentration

not linear

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Gas-phase-units

$$\frac{N_A}{K_y} = \left(y_{Ab} - y_A^*(x_{Ab})\right) = a + b = (y_{Ab} - y_{Ai}) + b$$

$$m' = \frac{\text{rise}}{\text{run}} = \frac{b}{(x_{Ai} - x_{Ab})}$$

$$\frac{N_A}{K_y} = (y_{Ab} - y_{Ai}) + m'(x_{Ai} - x_{Ab})$$

$$\frac{N_A}{K_y} = \frac{N_A}{k_y} + m'\left(\frac{N_A}{k_x}\right)$$

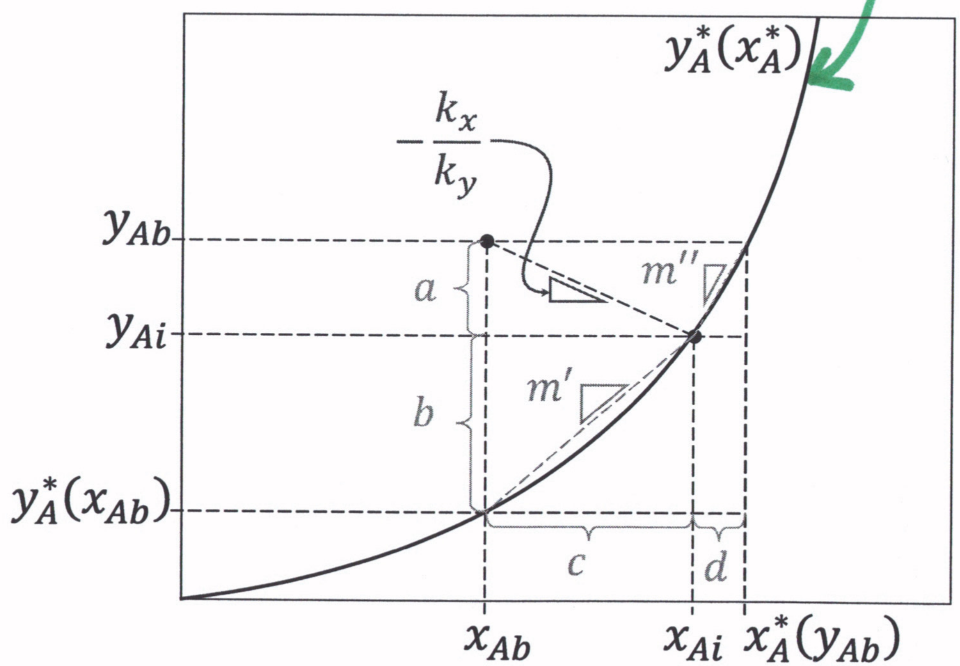
$$\frac{1}{K_y} = \frac{1}{k_y} + \frac{m'}{k_x}$$

GAS

$$\boxed{K_y = \frac{1}{\frac{1}{k_y} + \frac{m'}{k_x}}}$$

WRF pp600-603

concentrated regime



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Liquid-phase-units

concentrated regime

$$\frac{N_A}{K_x} = \left(x_A^*(y_{Ab}) - x_{Ab}\right) = c + d = \left(x_{Ai} - x_{Ab}\right) + d$$

$$m'' = \frac{\text{rise}}{\text{run}} = \frac{y_{Ab} - y_{Ai}}{d}$$

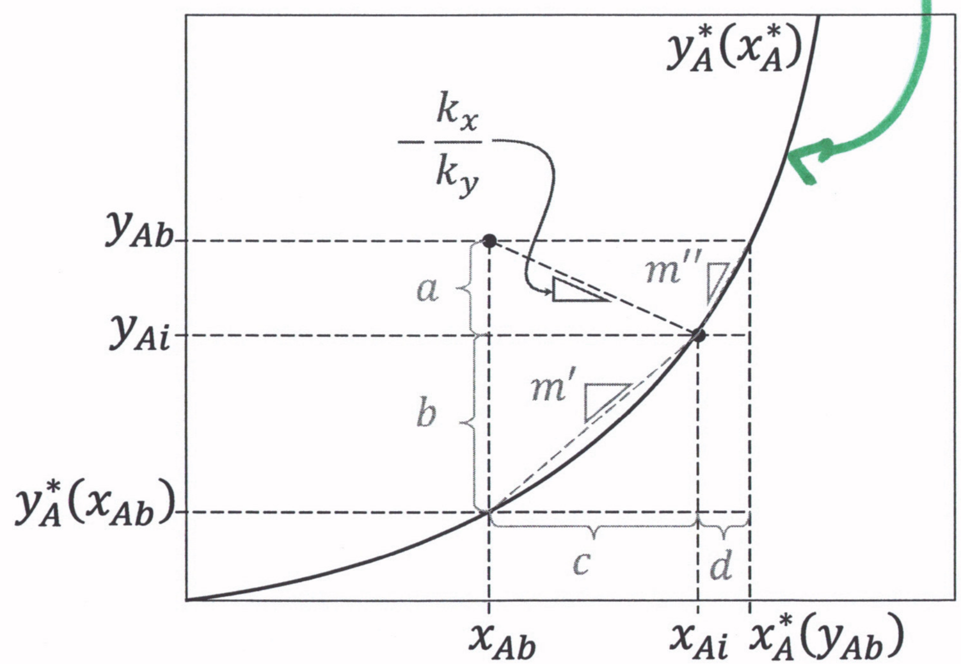
$$\frac{N_A}{K_x} = \left(x_{Ai} - x_{Ab}\right) + \frac{(y_{Ab} - y_{Ai})}{m''}$$

$$\frac{N_A}{K_x} = \frac{N_A}{k_x} + \frac{1}{m''}\left(\frac{N_A}{k_y}\right)$$

$$\frac{1}{K_x} = \frac{1}{k_x} + \frac{1}{m'' k_y}$$

$$\boxed{K_x = \frac{1}{\dfrac{1}{k_x} + \dfrac{1}{m'' k_y}}}$$

LIQUID



Definitions of:

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Film

Liquid-phase-units
Film Linear driving force model:

$$N_A \equiv k_x\left(x_{A,i} - x_{A,b}\right)$$
$$N_A \equiv k_{cL}\left(c_{AL,i} - c_{AL,b}\right)$$

Gas-phase-units:
Film Linear driving force model:

$$N_A \equiv k_p\left(p_{A,b} - p_{A,i}\right)$$
$$N_A \equiv k_{cG}\left(c_{AG,b} - c_{A,i}\right)$$
$$N_A \equiv k_y\left(y_{A,b} - y_{A,i}\right)$$

Overall

Liquid-phase-units
Overall Linear driving force model:

$$N_A \equiv K_x\left(x_A^*(\ \ ) - x_{A,b}\right)$$
$$N_A \equiv K_{cL}\left(c_{AL}^*(\ \ ) - c_{AL,b}\right)$$

$$(\ \ ) = p_{A,b} \text{ or } c_{A,b} \text{ or } y_{A,b}$$

Gas-phase-units:
Overall Linear driving force model:

$$N_A \equiv K_p\left(p_{A,b} - p_A^*(\ \ )\right)$$
$$N_A \equiv K_{cG}\left(c_{AG,b} - c_{AG}^*(\ \ )\right)$$
$$N_A \equiv K_y\left(y_{A,b} - y_A^*(\ \ )\right)$$

$$(\ \ ) = x_{A,b} \text{ or } c_{AL,b}$$

Let's take these tools out for a spin!

$$\boxed{K_x = \frac{1}{\frac{1}{k_x} + \frac{1}{m''k_y}}}, \quad \boxed{K_y = \frac{1}{\frac{1}{k_y} + \frac{m'}{k_x}}}, \text{ etc.}$$

mass xfer coefficients