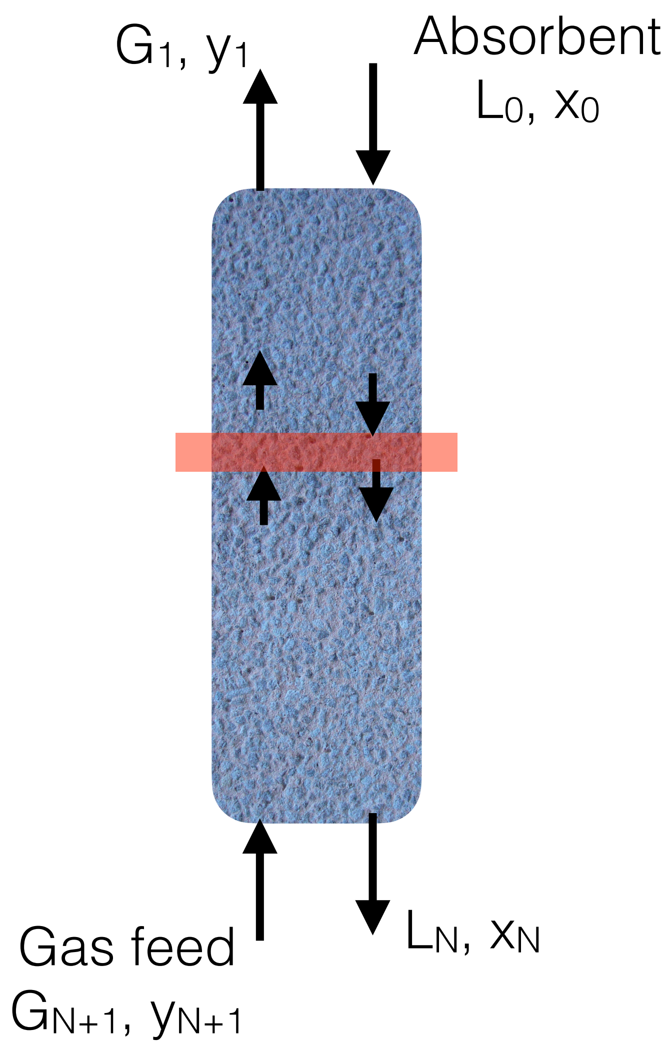
Review quiz

Consider the following case of mass balance on an absorption column where a gas is being absorbed. Which of the following statements is incorrect.



A. $G_1 > G_{N+1}$

B. $G_1 < G_{N+1}$

C. $L_0 < L_N$

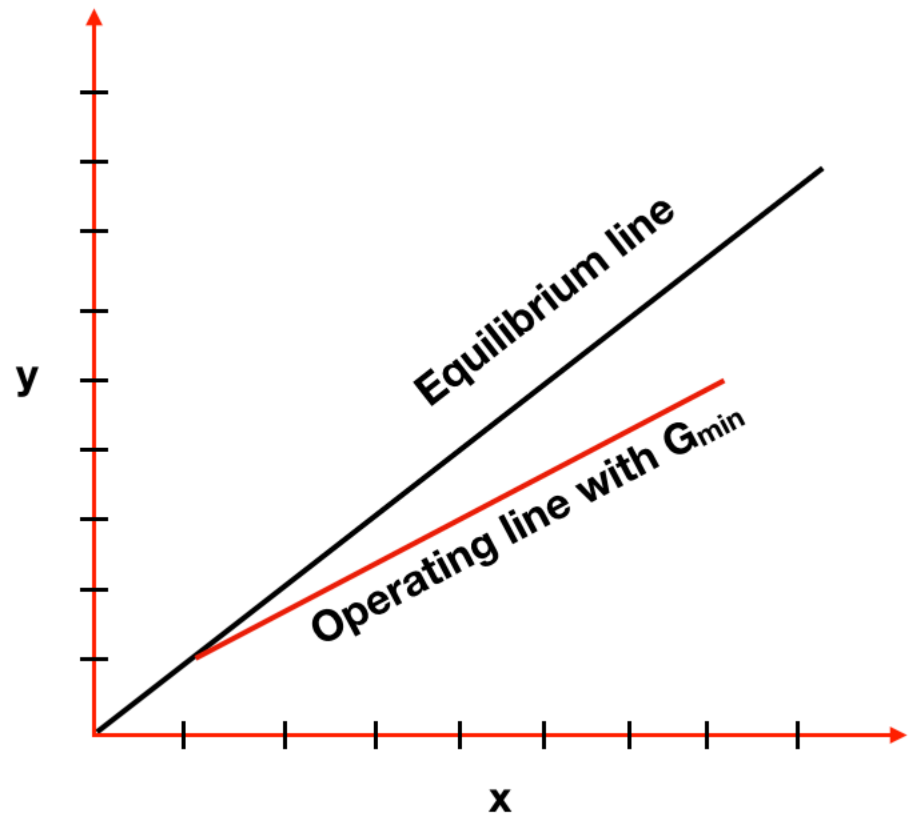
D. Mass transfer takes place from gas to liquid

EPFL

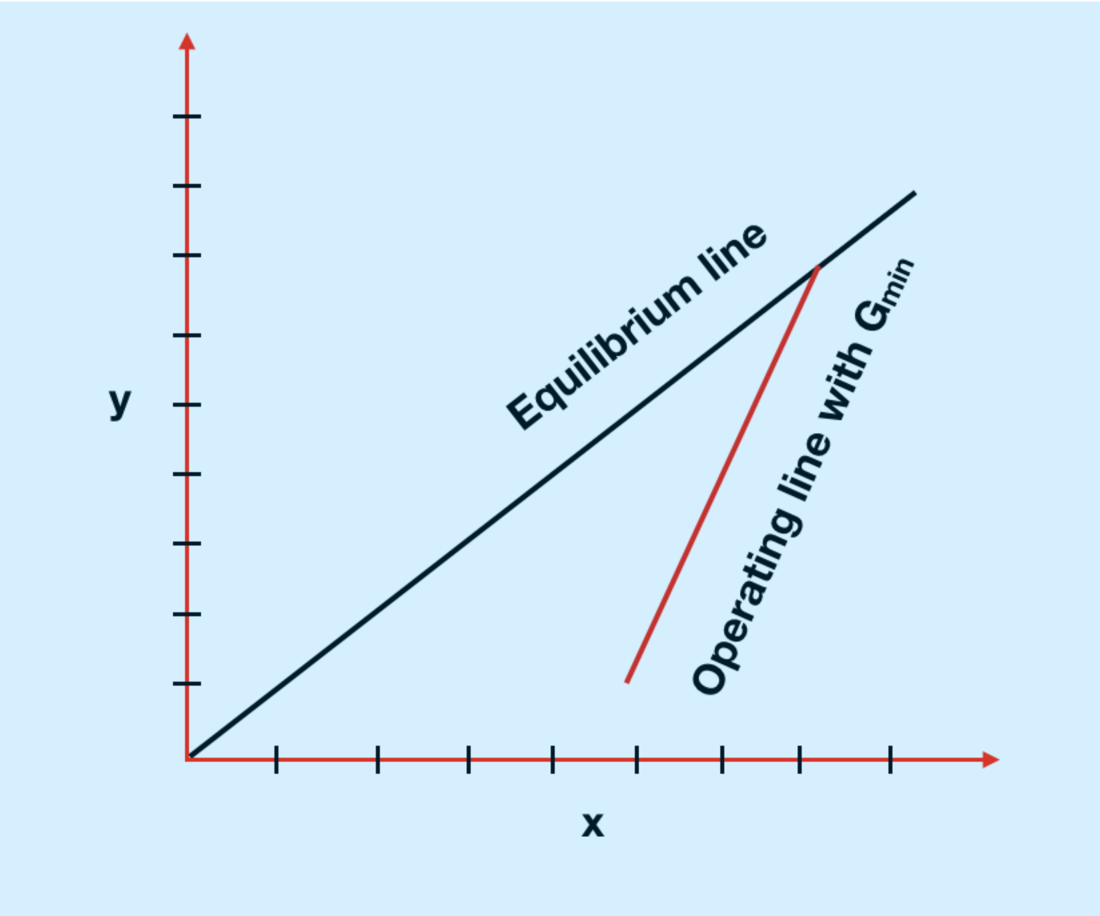
Review quiz

Which one of the following represents minimum gas flow rate for stripping (countercurrent operation)

A



B



Review quiz

In the following expression, which one of the statements is not true

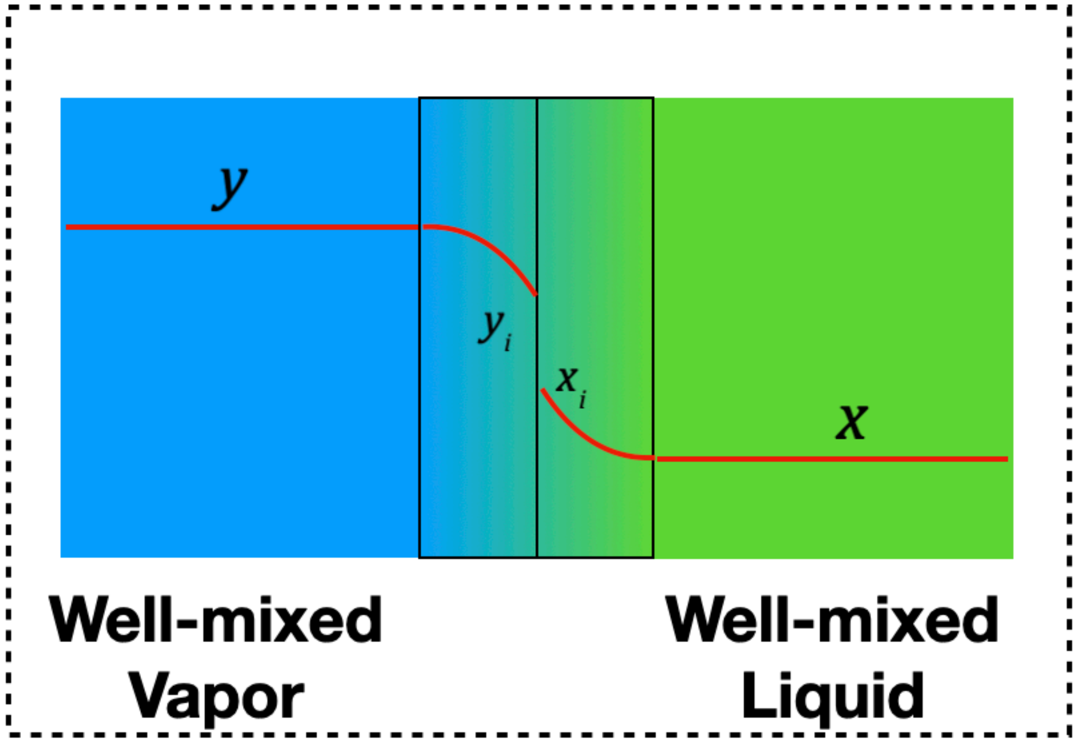
$$N = K_y A\left(y - mx\right) = K_x A\left(\frac{y}{m} - x\right)$$

A. $y = y_i$

B. $x = x_i$

C. x and y are not interfacial concentrations

D. $K_x = K_y$



Review quiz

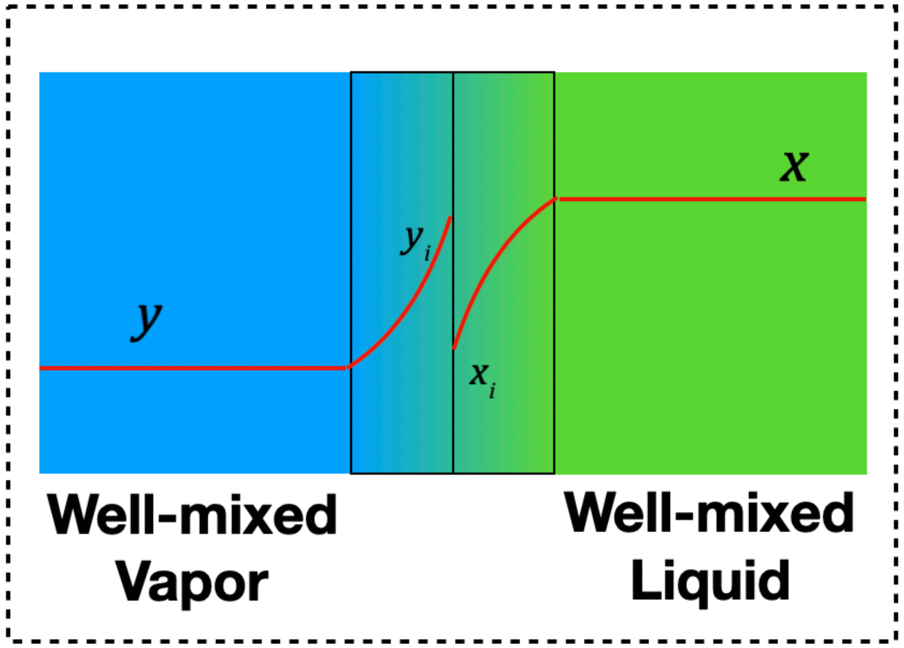
What is the direction of mass transfer in this case?

A. Vapor to liquid.

B. Liquid to vapor.

C. Both directions.

D. The net mass transfer is zero.



In-class exercise problem

A natural gas from a well in offshore Norway has CO_2 concentration of 3% (molar basis). CO_2 needs to be captured and sequestrated to curb global warming. Therefore, the gas needs to be treated to reduce CO_2 concentration to 0.1%. For this, you decided to create a pilot plant test using a packed bed absorption column contacting with liquid amine at 25 °C in a countercurrent fashion. The height of column is 1.0 meter and its cross-sectional area is 0.1 m^2. An amine is available as an absorbent but has 0.01% of CO_2. The equilibrium relationship for absorption of CO_2 in the amine can be described by $y_i = mx_i$ where m = 2. You decided to use 100 mole/s of this amine absorbent to treat 10 mole/s of natural gas. You have designed the system to perfection and equilibrium is established at the contact between the gas phase and the liquid phase. Assuming the case of dilute absorption:

1. Calculate the concentration of CO_2 in the outlet stream of the amine.
2. Calculate HTU and NTU.
3. Calculate the gas phase overall mass transfer coefficient, Kya.

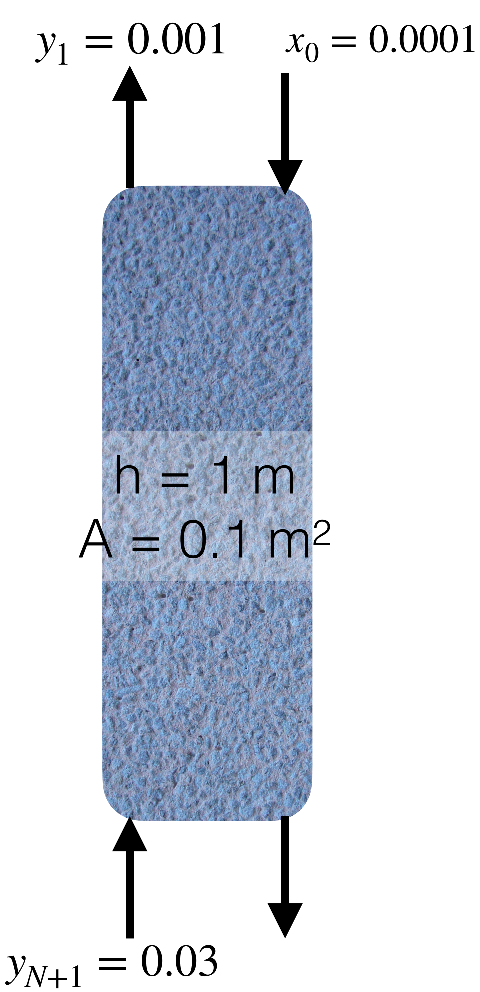
$$L(x_N - x_0) = G(y_{N+1} - y_1)$$

$$x_N = x_0 + \frac{G}{L}(y_{N+1} - y_1)$$

$y_{N+1} = 0.03$ $\quad y_1 = 0.001$ $\quad x_0 = 0.0001$

$G = 10$ mole/s $\quad L = 100$ mole/s

$$\Rightarrow x_N = 0.0001 + 0.1 * 0.029 = 0.003$$



$$NTU = \left(\frac{1}{1 - \frac{mG}{L}}\right)\ln\left(\frac{y_{N+1} - mx_N}{y_1 - mx_0}\right) = \left(\frac{1}{1 - \frac{2*10}{100}}\right)\ln\left(\frac{0.03 - 2*0.003}{0.001 - 2*0.0001}\right) = 4.25$$

$$h = HTU * NTU \qquad \Rightarrow HTU = h/NTU = 1/4.25 = 0.23\ m$$

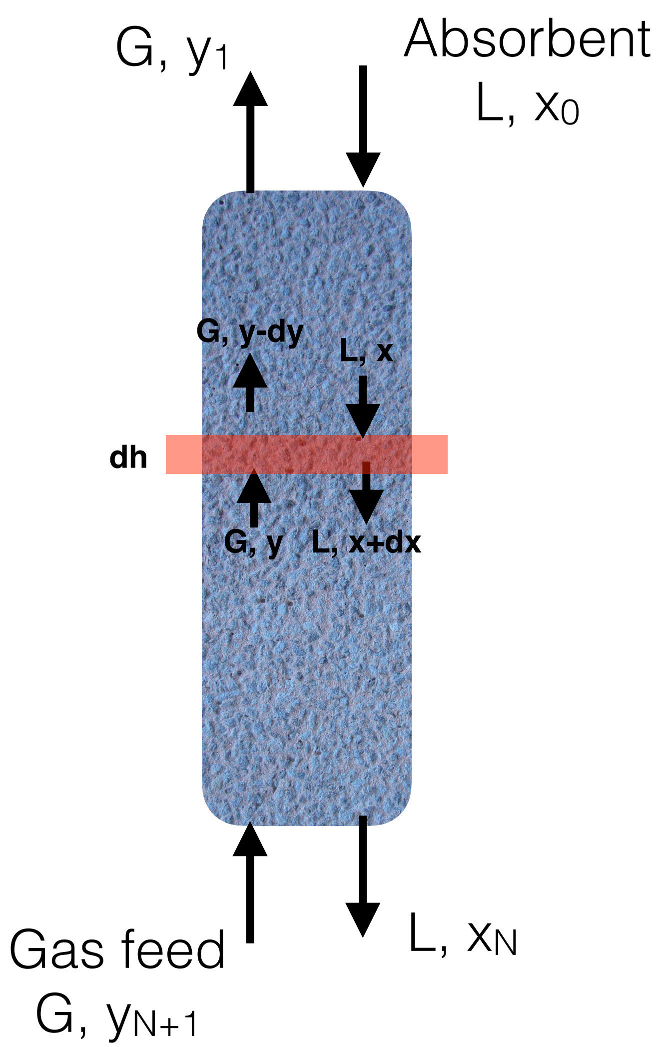
$$HTU = \frac{G}{K_y a A} = \frac{10}{K_y a * 0.1} \qquad \Rightarrow K_y a = 100/HTU = 425\ \text{mol/m}^3\text{/s}$$

In-class exercise problem

Consider the problem of countercurrent absorption of a gas (dilute in concentration) in a liquid absorbent. Derive an expression for the needed height of the column in terms of the adsorbent flow rate (L) and the overall mass transfer coefficient on the liquid side (Kx).

Hint: setup mass transfer as we did in the lecture video. The final expression should be

$$h = \frac{L}{K_x a A}\left[\left(\frac{1}{\frac{L}{mG}-1}\right)\ln\left(\frac{y_{N+1}-m x_N}{y_1 - m x_0}\right)\right]$$

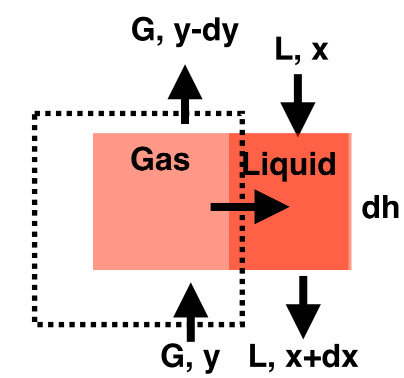


Overall balance on the element

Accumulation = in - out

$$0 = \left(Gy + Lx\right) - \left(G\left(y-dy\right)+L\left(x+dx\right)\right)$$

$$Gdy = Ldx$$



Applying mass transfer concept

Accumulation = in - out

$$x^* = y/m$$

a = surface area per unit volume

Adh = volume available for mass exchange

$$0 = Lx + K_x(x^* - x)aAdh - (x+dx)L$$

$$\Rightarrow \int_{x_0}^{x_N} \frac{L}{K_x a A}\frac{dx}{\left(\frac{y}{m}-x\right)} = \int_0^h dh$$

$$\Rightarrow h = \int_{x_0}^{x_N} \frac{L}{K_x a A}\frac{dx}{\left(\frac{y}{m}-x\right)}$$

EPFL

$$\Rightarrow h = \int_{x_0}^{x_N} \frac{L}{K_x a A} \frac{dx}{\left(\frac{y}{m} - x\right)}$$

substitute $y = \frac{L}{G} x + \left(y_1 - \frac{L}{G} x_0 \right)$

$$\Rightarrow h = \frac{L}{K_x a A} \int_{x_0}^{x_N} \frac{dx}{\left(\frac{1}{m}\left[\frac{L}{G}x + \left(y_1 - \frac{L}{G}x_0\right)\right] - x\right)}$$

$$\Rightarrow h = \frac{L}{K_x a A} \int_{x_0}^{x_N} \frac{dx}{\left[x\left(\frac{L}{mG} - 1\right) + \left(\frac{y_1}{m} - \frac{L}{mG}x_0\right)\right]}$$

$$\int (ax+b)^{-1} dx = \frac{\ln(ax+b)}{a}$$

$$\Rightarrow h = \frac{L}{K_x a A} \frac{1}{\left(\frac{L}{mG} - 1\right)} \ln\left[\left(\frac{L}{mG} - 1\right)x + \frac{y_1}{m} - \frac{L}{mG}x_0\right] \Big|_{x_0}^{x_N}$$

$$\Rightarrow h = \frac{L}{K_x a A} \frac{1}{\left(\frac{L}{mG} - 1\right)} \ln\left[\frac{\left(\frac{L}{mG} - 1\right)x_N + \frac{y_1}{m} - \frac{L}{mG}x_0}{\left(\frac{L}{mG} - 1\right)x_0 + \frac{y_1}{m} - \frac{L}{mG}x_0}\right]$$

<u>From operating line</u>

$$y_1 - \frac{L}{G}x_0 = y_{N+1} - \frac{L}{G}x_N$$

$$\Rightarrow h = \frac{L}{K_x a A} \frac{1}{\left(\frac{L}{mG} - 1\right)} \ln\left[\frac{\left(\cancel{\frac{L}{mG}} - 1\right)x_N + \frac{y_{N+1}}{m} - \cancel{\frac{L}{mG}x_N}}{\left(\cancel{\frac{L}{mG}} - 1\right)x_0 + \frac{y_1}{m} - \cancel{\frac{L}{mG}}x_0}\right]$$

$$h = \frac{L}{K_x a A}\left[\left(\frac{1}{\frac{L}{mG} - 1}\right)\ln\left(\frac{y_{N+1} - m x_N}{y_1 - m x_0}\right)\right]$$

EPFL