Advanced Diffusional Separation Processes

Gas absorption and stripping

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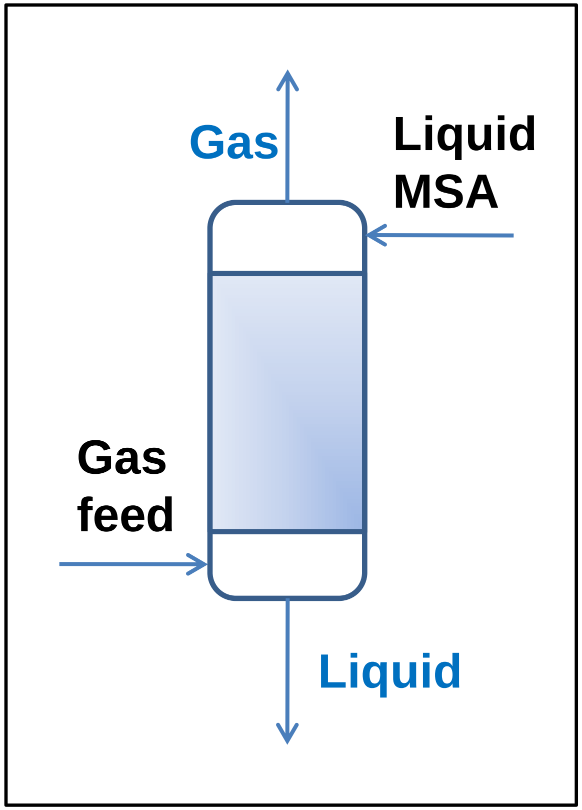
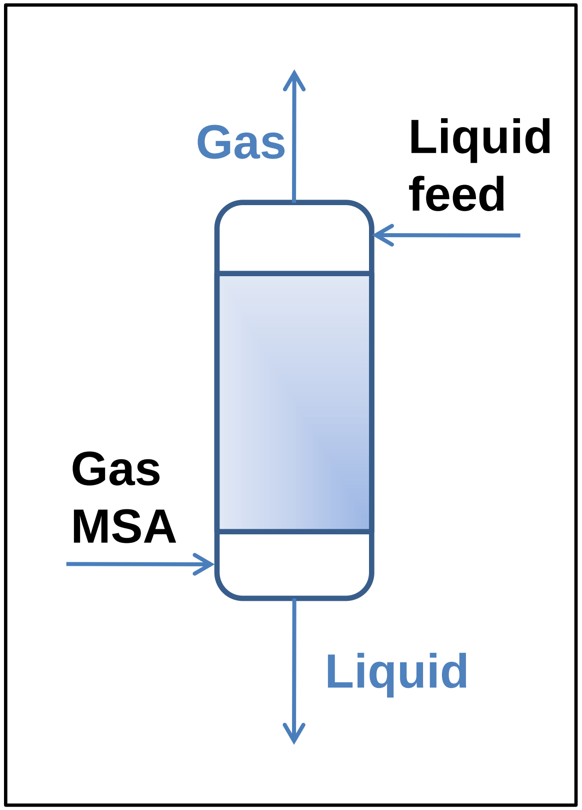
Absorption and stripping



Absorption

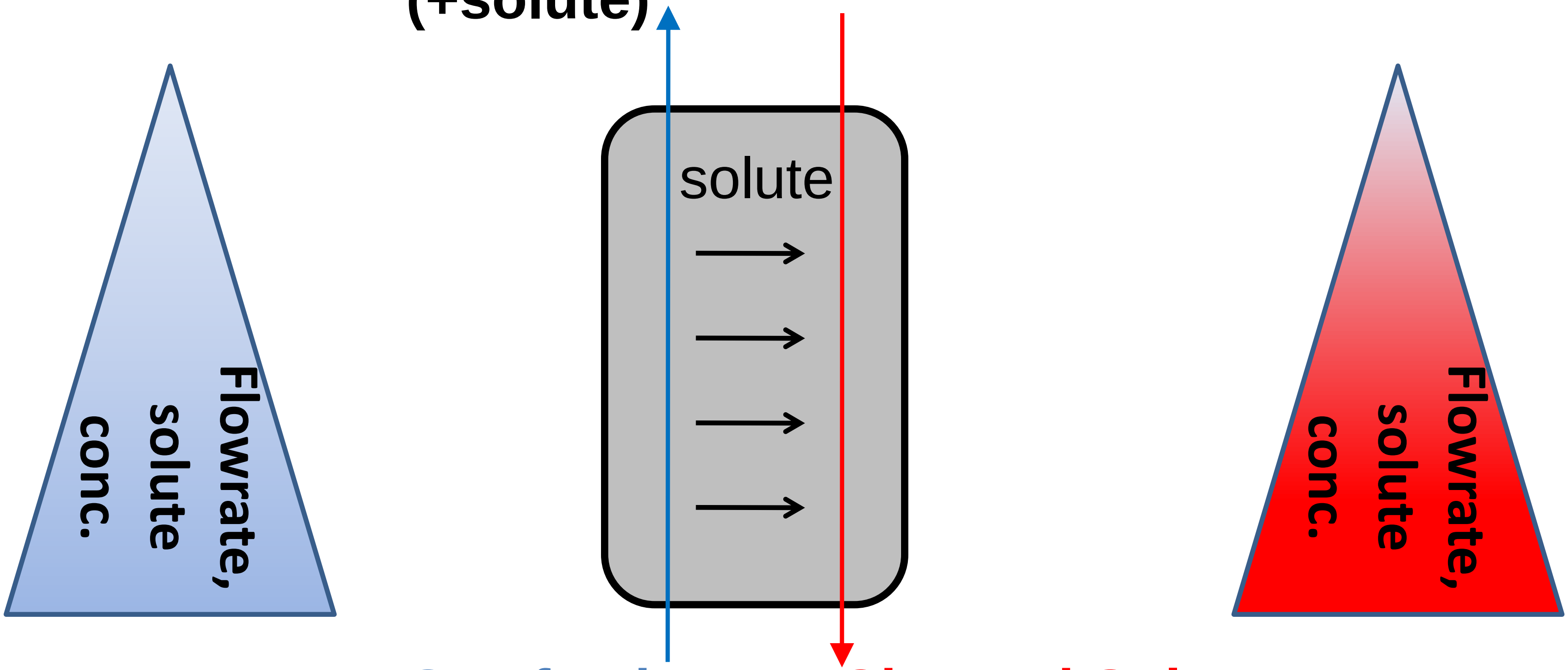


Stripping

Absorption column

Clean off-gas
carrier gas
(+solute)

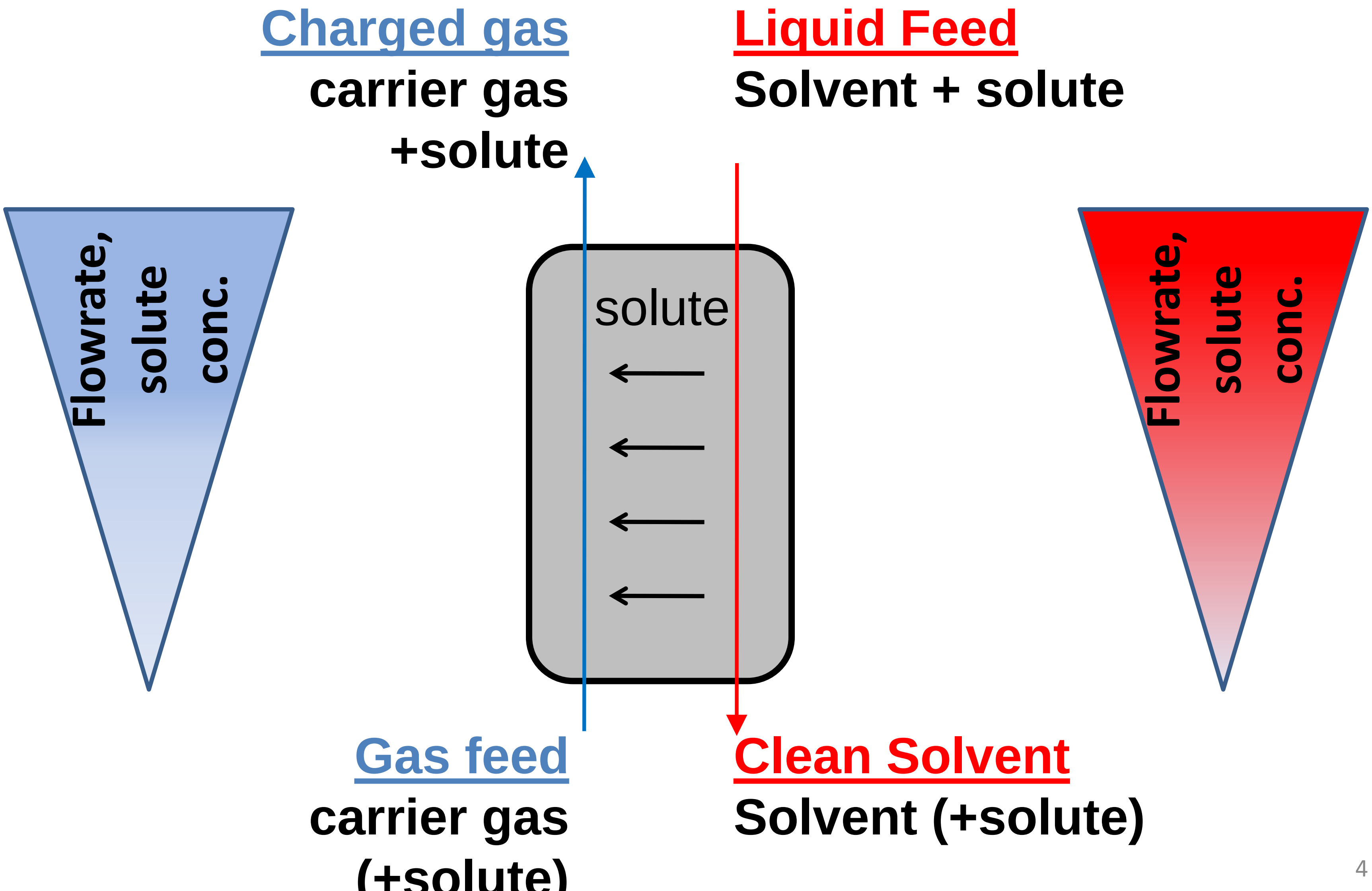
Liquid Solvent Feed
solvent (+solute)



Gas feed
carrier gas
+solute

Charged Solvent
solvent+solute

Stripping column

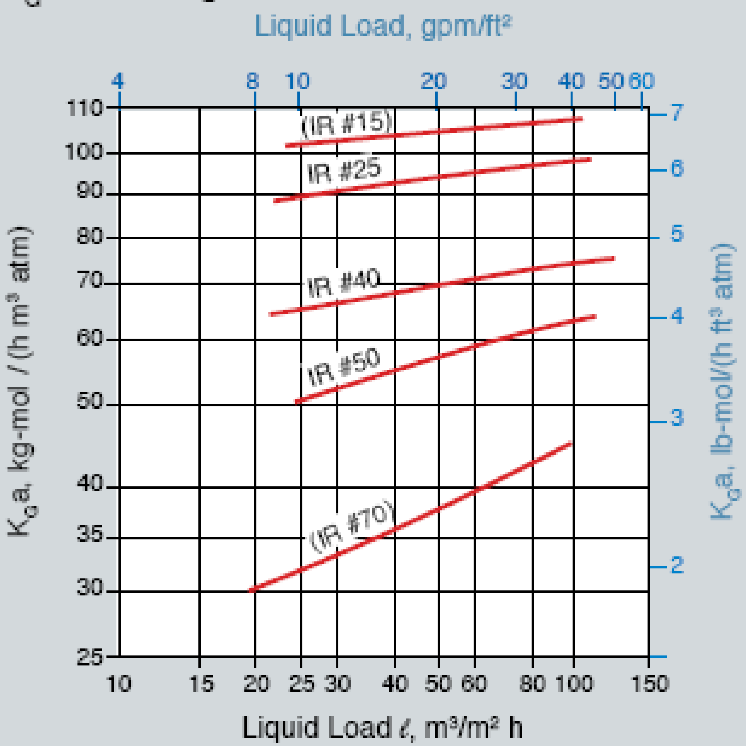


Random packing separation efficiency (ex: I-Ring)

Rate-based approach
K_G=mass transfer coeff.

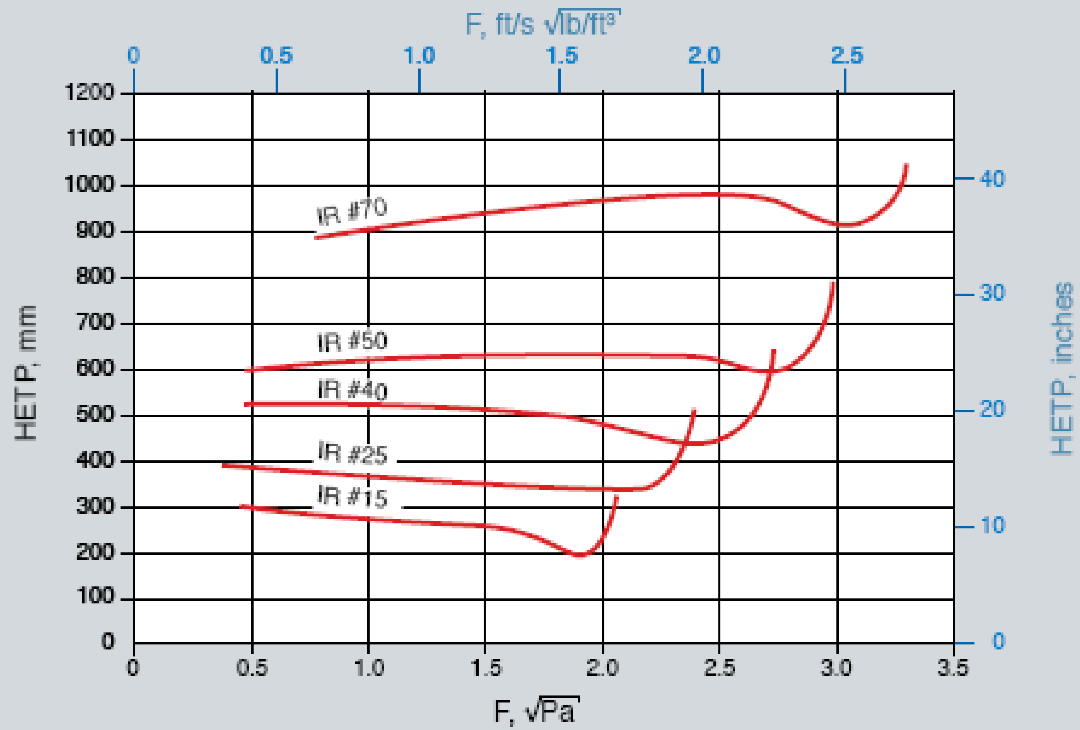
Equilibrium-stage approach
HETP=height equivalent to a theoretical plate

K_Ga of I-Ring



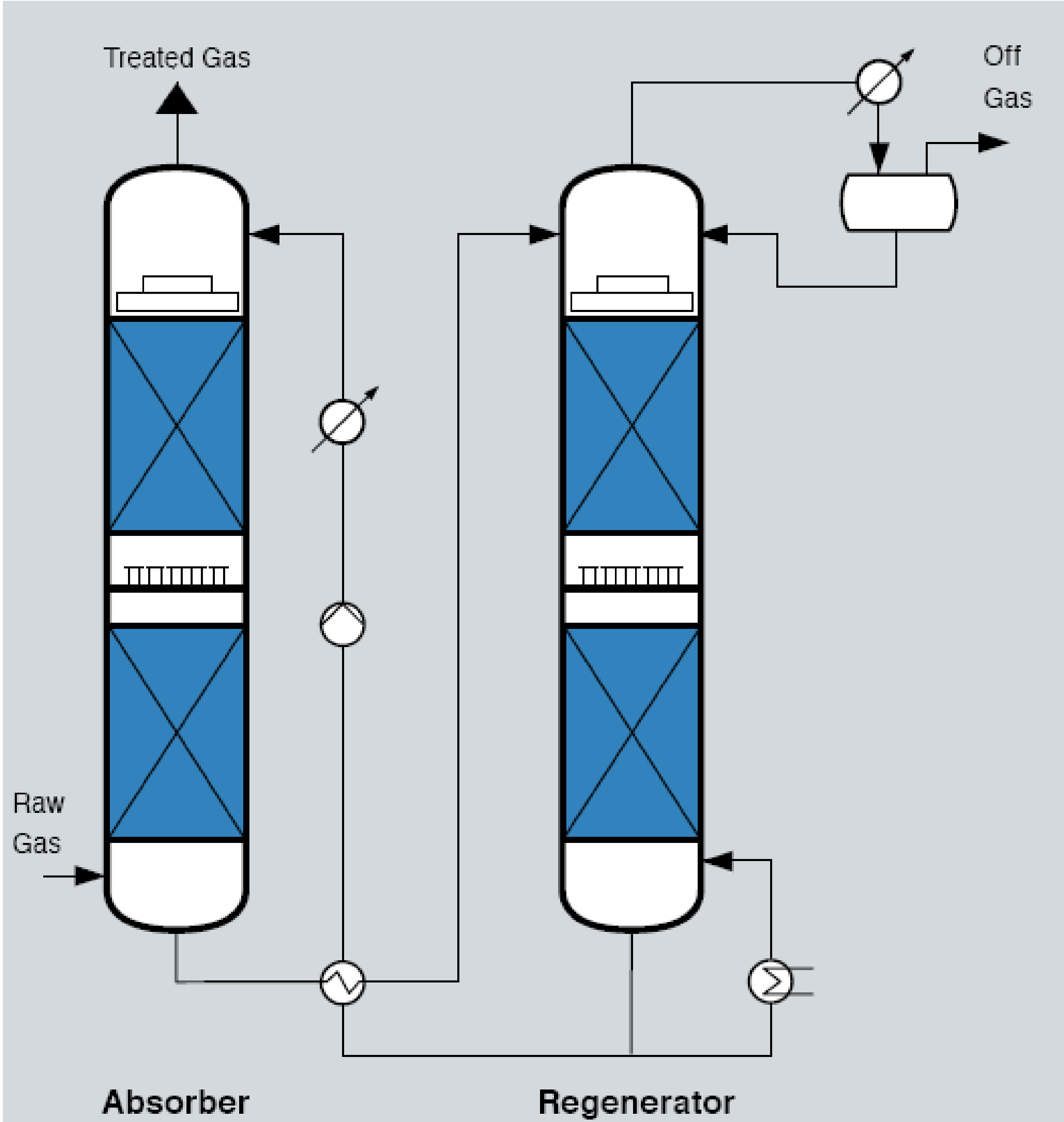
Conditions
Diameter: 0.3 m, Bed height: 2.25 m
Liquid concentration: 4% NaOH
Conversion to carbonate (Na_2CO_3): < 1%
Inlet gas concentration: 400ppm CO_2
Temperature: 25 °C
F = 1.5 √Pa
Bracket indicates extrapolated data

HETP of I-Ring



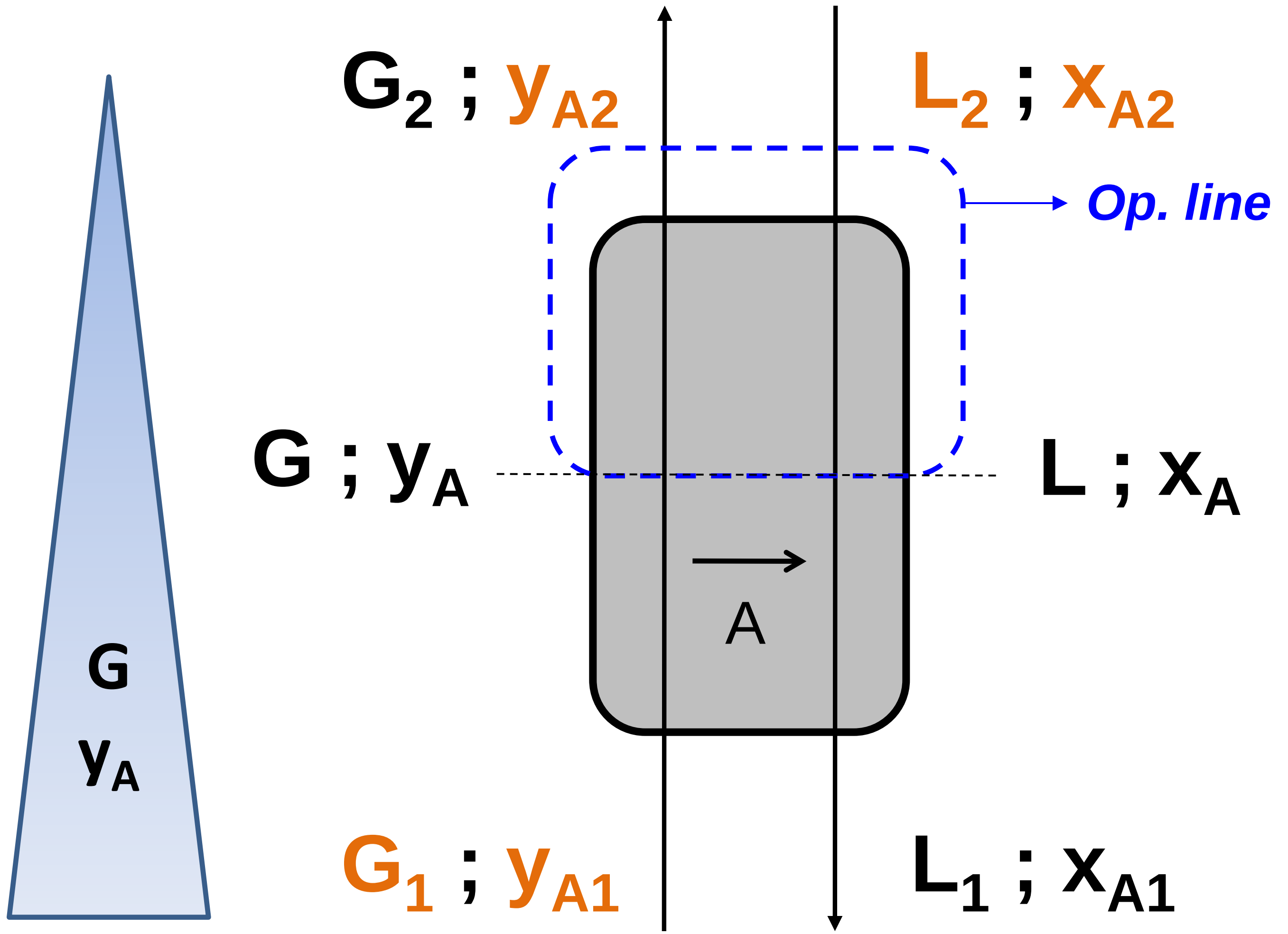
Conditions
Valid for atmospheric distillation with standard organic test mixture at total reflux.

$$\text{F-factor}: F = u\sqrt{\rho_G} \quad \left[\frac{m}{s}\sqrt{\frac{kg}{m^3}}\right]$$


Treated Gas
Off
Gas
Raw
Gas
Absorber
Regenerator

Absorption

Orange=known variable **A=solute**



Determination of the 3 unknowns G_2, L_1, x_{A1}

Mass balance on carrier gas

$$G_1(1-y_{A1}) = G_2(1-y_{A2}) \Rightarrow G_2 = \frac{G_1(1-y_{A1})}{(1-y_{A2})}$$

Total mass balance

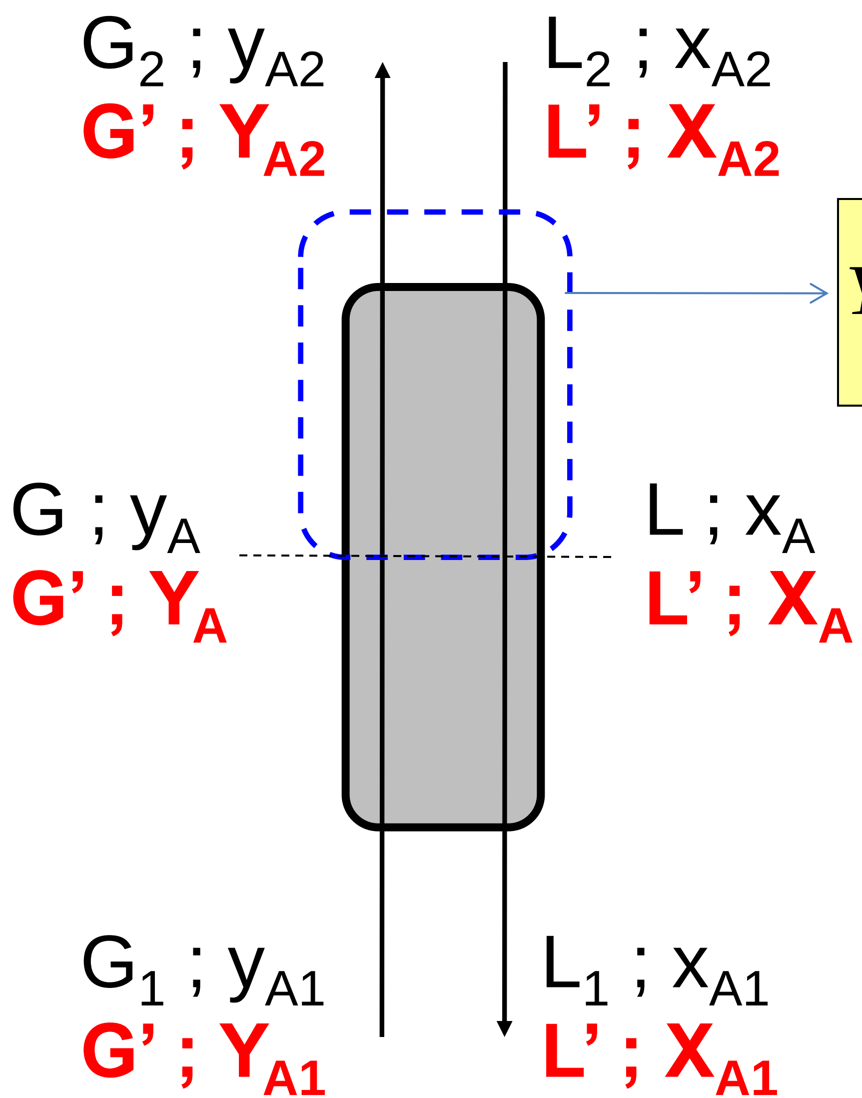
$$L_1 + G_2 = L_2 + G_1 \Rightarrow L_1 = L_2 + G_1 - G_2$$

Mass balance on solute

$$L_1 x_{A1} + G_2 y_{A2} = L_2 x_{A2} + G_1 y_{A1}$$

$$\Rightarrow x_{A1} = \frac{L_2 x_{A2} + G_1 y_{A1} - G_2 y_{A2}}{L_1}$$

Absorption: use of molar ratios



Operating line

$$Y_A = Y_{A2} + \frac{L'}{G'}\left(X_A - X_{A2}\right)$$

Molar ratios

$$Y_A = \frac{y_A}{1-y_A}$$

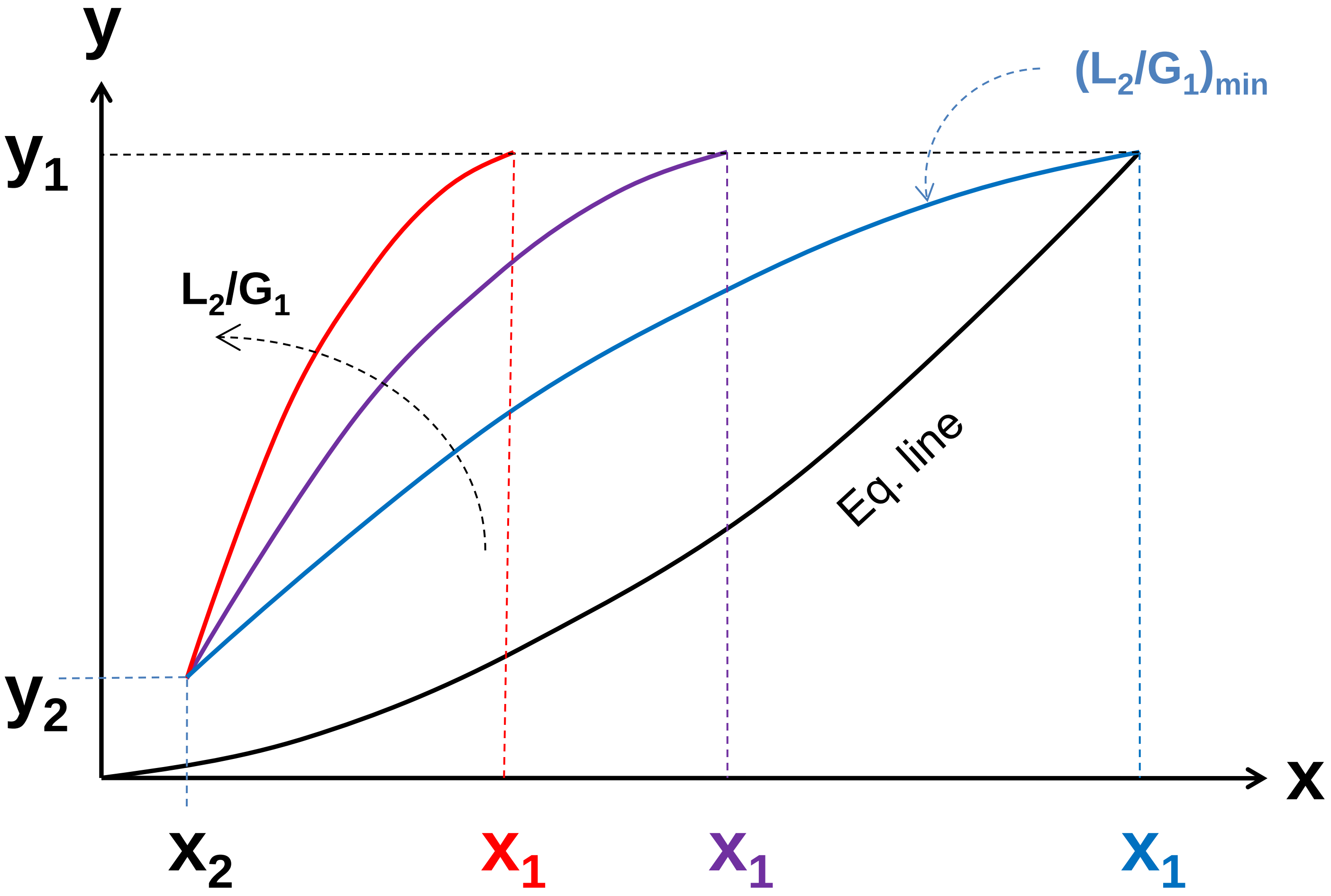
$$X_A = \frac{x_A}{1-x_A}$$

Solvent and carrier gas flowrates

$$L' = L\left(1-x_A\right)$$

$$G' = G\left(1-y_A\right)$$

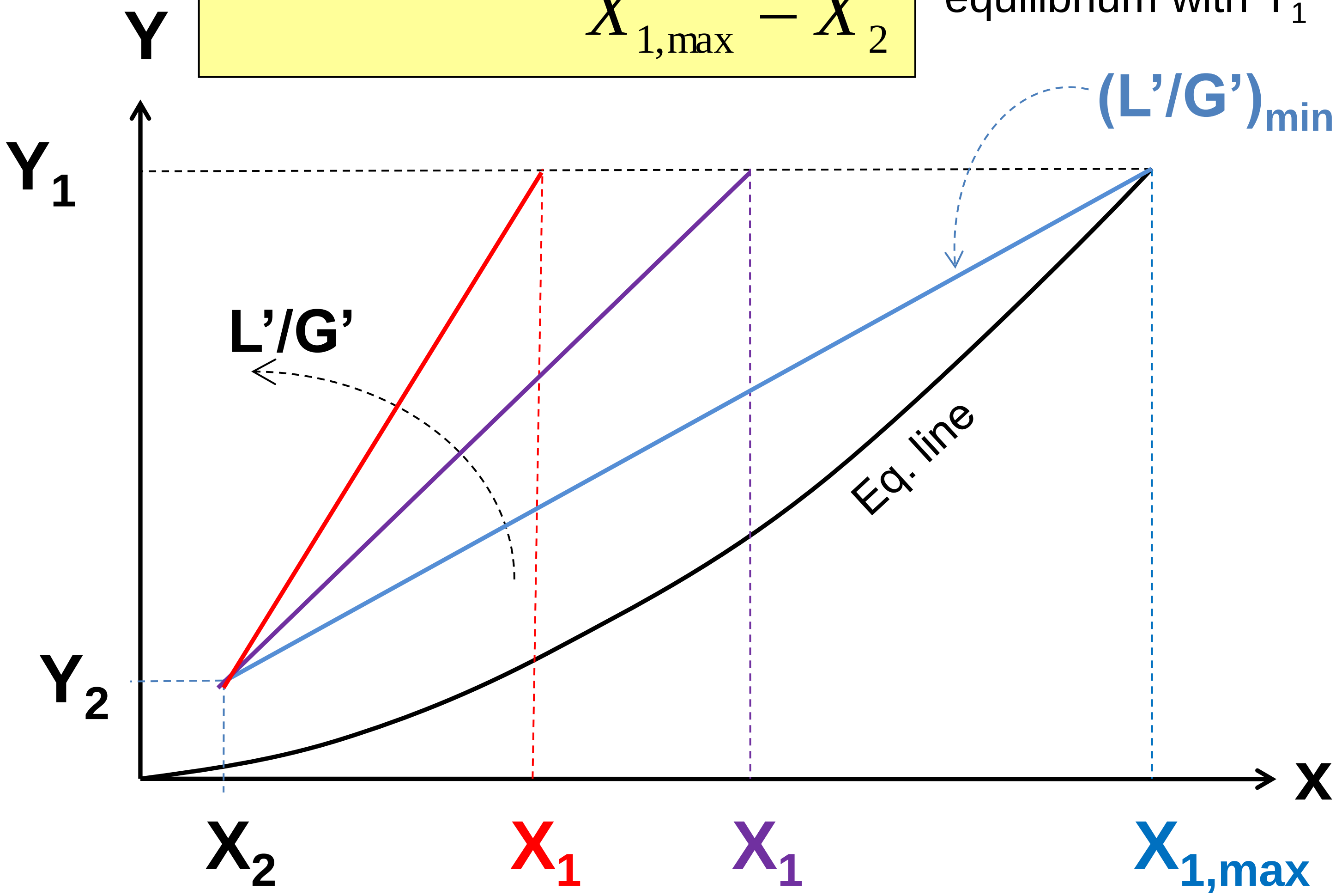
Effect of solvent flowrate on x_1



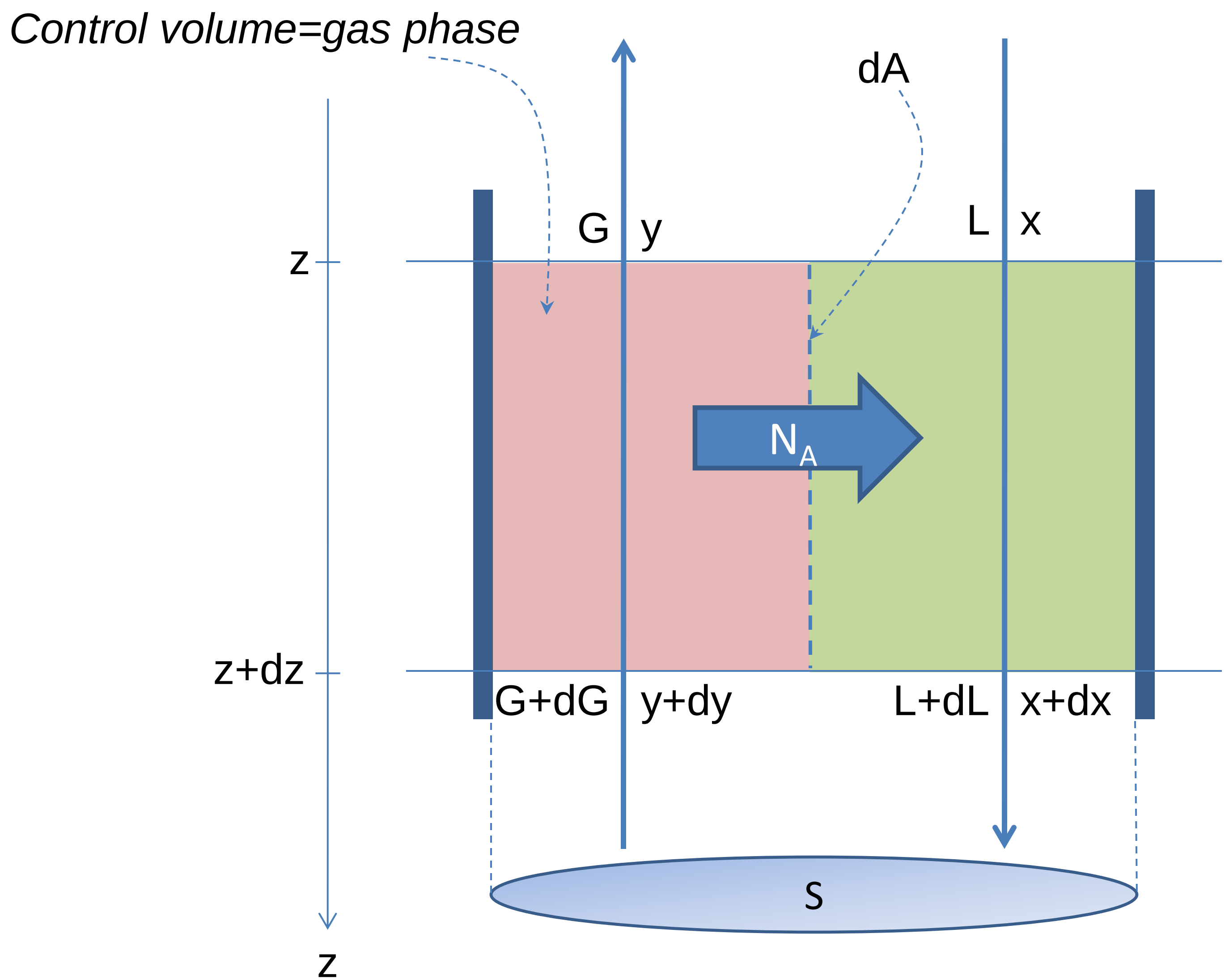
Effect of solvent flowrate on X_1

$$(L'/G')_{min} = \frac{Y_1 - Y_2}{X_{1,max} - X_2}$$

Where $X_{1,max}$ is at equilibrium with Y_1



Absorber design (column height)



Absorber design (column height)

Mass balance on solute in gas phase

$$\overbrace{\left[Gy+d(Gy)\right]S}^{\text{IN (convection)}} = \overbrace{GyS}^{\substack{\text{OUT} \\ \text{(convection)}}} + \overbrace{N_A dA}^{\substack{\text{OUT} \\ \text{(mass transfer)}}} \qquad (1)$$

Total mass balance on gas phase

$$\overbrace{(G+dG)S}^{\text{IN (convection)}} = \overbrace{GS}^{\substack{\text{OUT} \\ \text{(convection)}}} + \overbrace{N_T dA}^{\substack{\text{OUT} \\ \text{(mass transfer)}}} \qquad (2)$$

Absorber height design equation

(2)➔ $$S\,dG = N_T dA = t_A N_A S\,a\,dz \Rightarrow dG = t_A N_A\,a\,dz$$

(1)➔ $$(Gy + Gdy + ydG)S = GyS + N_A\,a\,S\,dz$$

$$Gdy + ydG = N_A\,a\,dz$$

$$Gdy + y\,t_A N_A\,a\,dz = N_A\,a\,dz$$

$$\boxed{\int_0^{h_T} dz = h_T = \int_{y_2}^{y_1} \frac{Gdy}{N_A\,a(1 - t_A\,y)}}$$

Absorber height design equation

The same approach based on differential mass balances on the liquid phase leads to:

$$h_T = \int_{x_2}^{x_1} \frac{L\,dx}{N_A\, a\left(1 - t_A\, x\right)}$$

General equations for absorber height based on individual film resistances

$$h_T = \int_{y_{A2}}^{y_{A1}} \frac{G}{k_G^o\, a\, P} \frac{(Y_f)_A}{1 - t_A y_A} \frac{dy_A}{y_A - y_{Ai}}$$

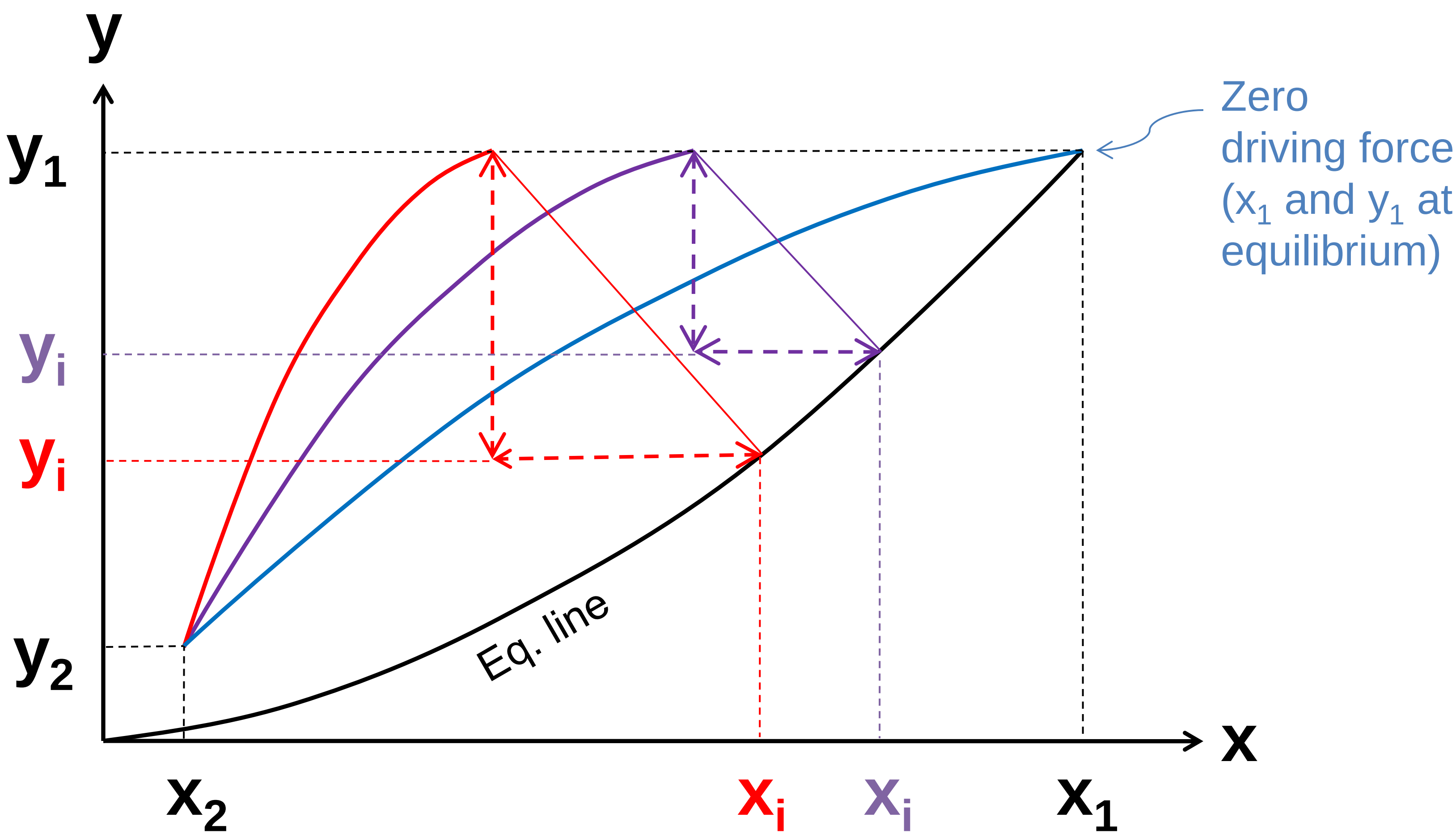
$$h_T = \int_{x_{A2}}^{x_{A1}} \frac{L}{k_L^o\, a\, \overline{\rho}_M} \frac{(X_f)_A}{1 - t_A x_A} \frac{dx_A}{x_{Ai} - x_A}$$

Equations for absorber height based on individual film resistances (UMD)

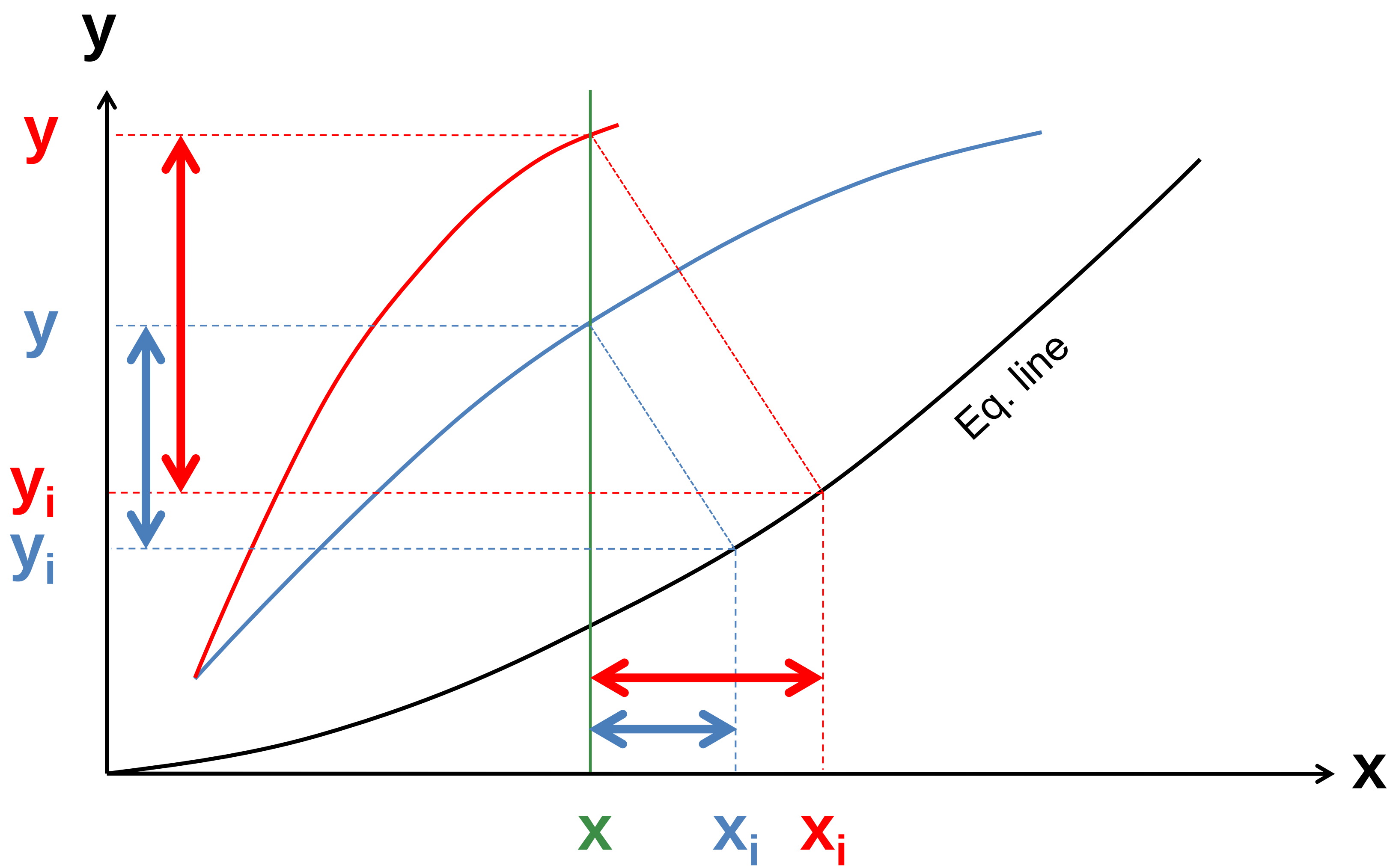
$$h_T = \int_{y_{A2}}^{y_{A1}} \frac{G}{k_G^o\, a\, P} \frac{y_{BM}}{1 - y_A} \frac{dy_A}{y_A - y_{Ai}}$$

$$h_T = \int_{x_{A2}}^{x_{A1}} \frac{L}{k_L^o\, a\, \overline{\rho}_M} \frac{x_{BM}}{1 - x_A} \frac{dx_A}{x_{Ai} - x_A}$$

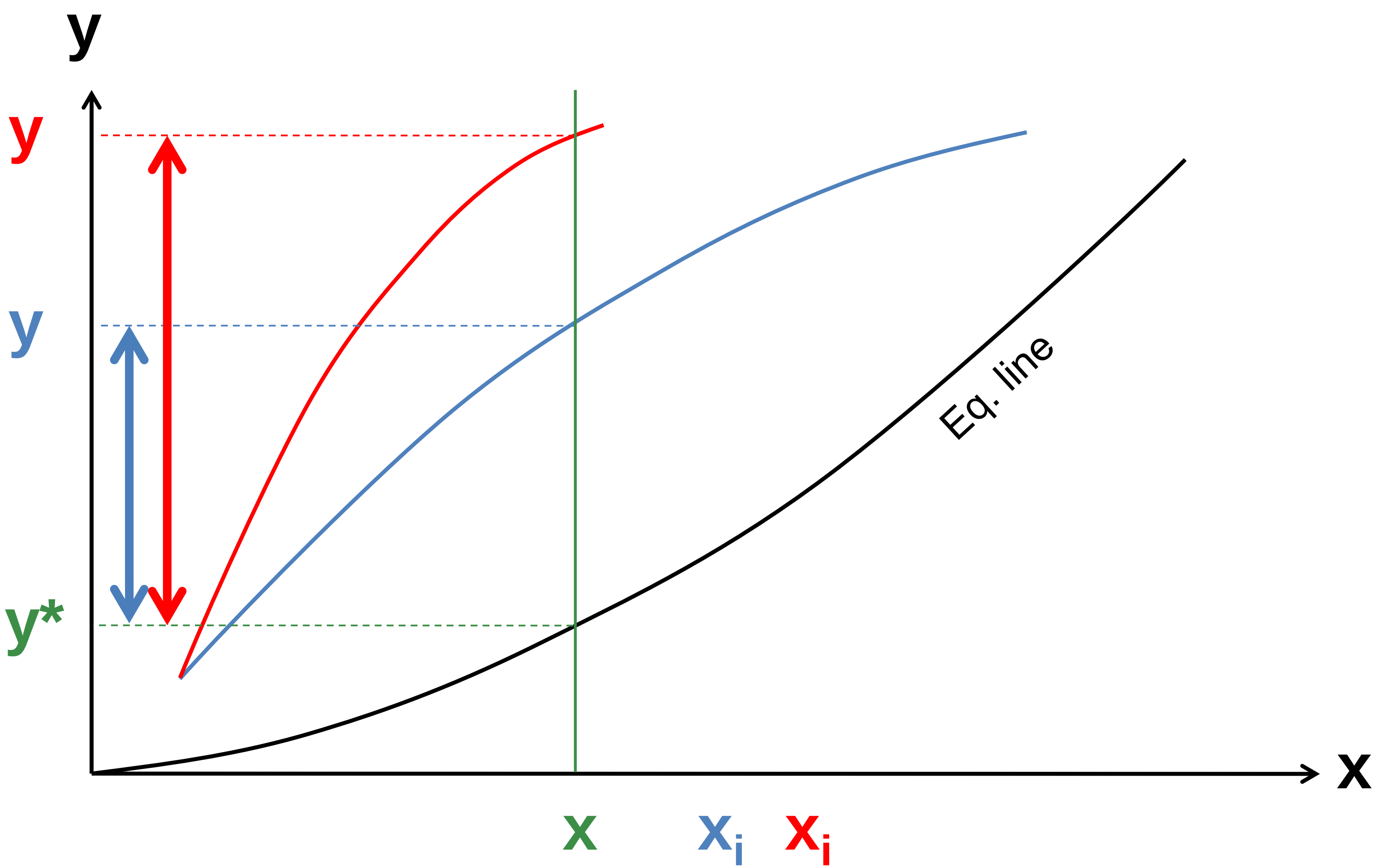
Effect of L/G on driving forces at column bottom



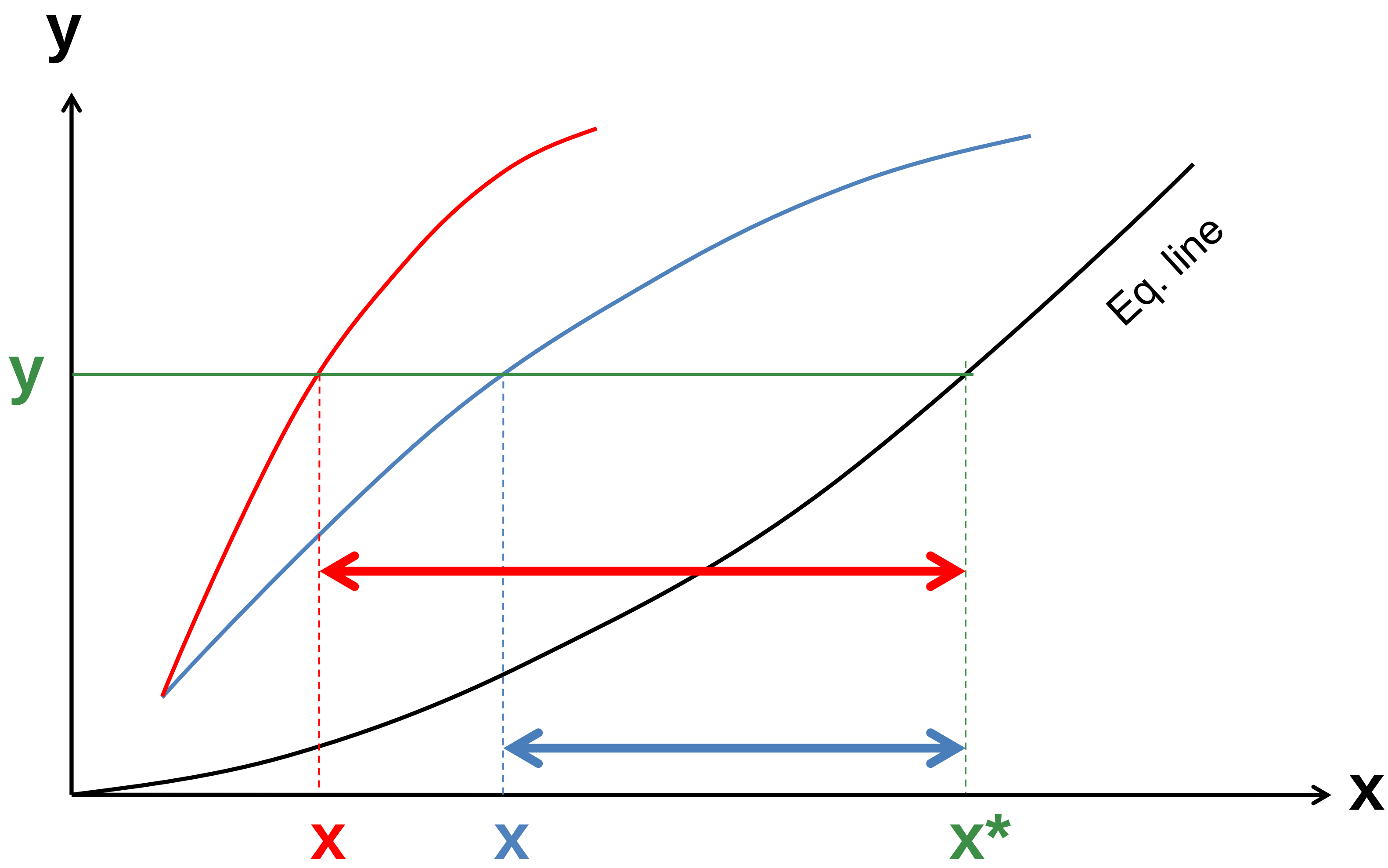
Effect of L/G on individual driving forces in column



Effect of L/G on overall driving force in column



Effect of L/G on overall driving force in column



HTU and NTU concepts (gas phase)

$$h_T = \int_{y_{A2}}^{y_{A1}} \frac{G}{k_G^o\, a\, P} \frac{y_{BM}}{1-y_A} \frac{dy_A}{y_A - y_{Ai}} = \frac{G}{k_G^o\, a\, P} \int_{y_{A2}}^{y_{A1}} \frac{y_{BM}}{1-y_A} \frac{dy_A}{y_A - y_{Ai}}$$

H_G N_G

$$h_T = \int_{y_{A2}}^{y_{A1}} \frac{G}{K_{OG}^o\, a\, P} \frac{y_{BM}^*}{1-y_A} \frac{dy_A}{y_A - y_A^*} = \frac{G}{K_{OG}^o\, a\, P} \int_{y_{A2}}^{y_{A1}} \frac{y_{BM}^*}{1-y_A} \frac{dy_A}{y_A - y_A^*}$$

H_{OG} N_{OG}

HTU and NTU concepts (liquid phase)

$$h_T = \int_{x_{A2}}^{x_{A1}} \frac{L}{k_L^o\, a\, \bar{\rho}_M} \frac{x_{BM}}{1 - x_A} \frac{dx_A}{x_{Ai} - x_A} = \frac{L}{k_L^o\, a\, \bar{\rho}_M} \int_{x_{A2}}^{x_{A1}} \frac{x_{BM}}{1 - x_A} \frac{dx_A}{x_{Ai} - x_A}$$

H_L N_L

$$h_T = \int_{x_{A2}}^{x_{A1}} \frac{L}{K_{OL}^o\, a\, \bar{\rho}_M} \frac{x_{BM}^*}{1 - x_A} \frac{dx_A}{x_A^* - x_A} = \frac{L}{K_{OL}^o\, a\, \bar{\rho}_M} \int_{x_{A2}}^{x_{A1}} \frac{x_{BM}^*}{1 - x_A} \frac{dx_A}{x_A^* - x_A}$$

H_{OL} N_{OL}

HTU and NTU concepts

$$\boxed{h_T = HTU \times NTU}$$

$$\boxed{\begin{aligned} h_T &= H_G \times N_G \\ h_T &= H_{OG} \times N_{OG} \\ h_T &= H_L \times N_L \\ h_T &= H_{OL} \times N_{OL} \end{aligned}}$$

Dilute cases

$$N_G = \int_{y_{A2}}^{y_{A1}} \frac{y_{BM}}{1-y_A} \frac{dy_A}{y_A - y_{Ai}} = \int_{y_{A2}}^{y_{A1}} \frac{dy_A}{y_A - y_{Ai}}$$

$$N_{OG} = \int_{y_{A2}}^{y_{A1}} \frac{y^*_{BM}}{1-y_A} \frac{dy_A}{y_A - y^*_A} = \int_{y_{A2}}^{y_{A1}} \frac{dy_A}{y_A - y^*_A}$$

$$N_L = \int_{x_{A2}}^{x_{A1}} \frac{x_{BM}}{1-x_A} \frac{dx_A}{x_{Ai} - x_A} = \int_{x_{A2}}^{x_{A1}} \frac{dx_A}{x_{Ai} - x_A}$$

$$N_{OL} = \int_{x_{A2}}^{x_{A1}} \frac{x^*_{BM}}{1-x_A} \frac{dx_A}{x^*_A - x_A} = \int_{x_{A2}}^{x_{A1}} \frac{dx_A}{x^*_A - x_A}$$

Overall film resistances

$$\frac{G}{K_{OG}^{o}\,a\,P} \qquad \frac{G}{k_{G}^{o}\,a\,P} \qquad \frac{L}{k_{L}^{o}\,a\,\bar{\rho}_{M}}$$

$$\frac{1}{K_{OG}^{0}} = \frac{1}{k_{G}^{0}} + \frac{m\,p}{k_{L}^{0}\,\bar{\rho}_{M}} \Rightarrow \boxed{H_{OG} = H_{G} + \frac{H_{L}}{A}}$$

$$A = \frac{L}{mG}$$

$$\frac{L}{K_{OL}^{o}\,a\,\bar{\rho}_{M}} \qquad \frac{L}{k_{L}^{o}\,a\,\bar{\rho}_{M}} \qquad \frac{G}{k_{G}^{o}\,a\,P}$$

$$\frac{1}{K_{OL}^{0}} = \frac{1}{k_{L}^{0}} + \frac{\bar{\rho}_{M}}{k_{G}^{0}\,m\,p} \Rightarrow \boxed{H_{OL} = H_{L} + A \times H_{G}}$$

Dilute cases: Colburn approach

When equilibrium and operating lines are straight

GAS PHASE

$$N_{OG} = A\frac{\ln\left\{\left[\left(\frac{A-1}{A}\right)\left(\frac{y_1 - mx_2}{y_2 - mx_2}\right) + \frac{1}{A}\right]\right\}}{A-1}$$

$$H_{OG} = H_G + \frac{H_L}{A}$$

$$h_T = H_{OG}N_{OG}$$

$$A = \frac{L}{mG}$$

LIQUID PHASE

$$N_{OL} = \frac{\ln\left\{(1-A)\left(\frac{y_1 - mx_2}{y_1 - mx_1}\right) + A\right\}}{1-A}$$

$$H_{OL} = H_L + AH_G$$

$$h_T = H_{OL}N_{OL}$$

$$A = \frac{L}{mG}$$

Dilute cases:
Mean driving force approach

When equilibrium and operating lines are straight

$$N_{OG} = \frac{y_1 - y_2}{\overline{(y - y^*)}_{LM}}$$

$$\overline{(y - y^*)}_{LM} = \frac{(y - y^*)_1 - (y - y^*)_2}{\ln \frac{(y - y^*)_1}{(y - y^*)_2}}$$

$$H_{OG} = H_G + \frac{H_L}{A}$$

$$h_T = H_{OG} N_{OG}$$

$$A = \frac{L}{mG}$$

$$N_{OL} = \frac{x_1 - x_2}{\overline{(x^* - x)}_{LM}}$$

$$\overline{(x^* - x)}_{LM} = \frac{(x^* - x)_1 - (x^* - x)_2}{\ln \frac{(x^* - x)_1}{(x^* - x)_2}}$$

$$H_{OL} = H_L + A H_G$$

$$h_T = H_{OL} N_{OL}$$

$$A = \frac{L}{mG}$$

$$h_T = \int_{y_{A2}}^{y_{A1}} \frac{G}{N_A a} \frac{dy_A}{1-t_A y_A}$$

2-film theory gas-film resistance

$$h_T = \int_{y_{A2}}^{y_{A1}} \frac{G}{k_G^o\, a\, P} \frac{(Y_f)_A}{1-t_A y_A} \frac{dy_A}{y_A - y_{Ai}}$$

UMD

$$h_T = \int_{y_{A2}}^{y_{A1}} \frac{G}{k_G^o\, a\, P} \frac{y_{BM}}{1-y_A} \frac{dy_A}{y_A - y_{Ai}}$$

Const. H_G

$$h_T = H_G \int_{y_{A2}}^{y_{A1}} \frac{y_{BM}}{1-y_A} \frac{dy_A}{y_A - y_{Ai}}$$

Dilute case

$$h_T = H_G \int_{y_{A2}}^{y_{A1}} \frac{dy_A}{y_A - y_{Ai}}$$

2-film theory overall gas-film resistance

$$h_T = \int_{y_{A2}}^{y_{A1}} \frac{G}{K_{OG}^o\, a\, P} \frac{(Y_f^*)_A}{1-t_A y_A} \frac{dy_A}{y_A - y_A^*}$$

UMD

$$h_T = \int_{y_{A2}}^{y_{A1}} \frac{G}{K_{OG}^o\, a\, P} \frac{y_{BM}^*}{1-y_A} \frac{dy_A}{y_A - y_A^*}$$

Const. H_{OG}

$$h_T = H_{OG} \int_{y_{A2}}^{y_{A1}} \frac{y_{BM}^*}{1-y_A} \frac{dy_A}{y_A - y_A^*}$$

Dilute case

$$h_T = H_{OG} \int_{y_{A2}}^{y_{A1}} \frac{dy_A}{y_A - y_A^*}$$

y*=mx ; const. m

$$h_T = H_{OG} \frac{A}{A-1} \ln\left\{\left(\frac{A-1}{A}\right)\left(\frac{y_1 - mx_2}{y_2 - mx_2}\right) + \frac{1}{A}\right\}$$

$$h_T = H_{OG} \frac{y_{A1} - y_{A2}}{\left(y_A - y_A^*\right)_{LM}}$$

$$h_T = \int_{x_{A2}}^{x_{A1}} \frac{L}{N_A a} \frac{dx_A}{1 - t_A x_A}$$

2-film theory liq.-film resistance

$$h_T = \int_{x_{A2}}^{x_{A1}} \frac{L}{k_L^o\, a\, \bar{\rho}_M} \frac{(X_f)_A}{1 - t_A x_A} \frac{dx_A}{x_{Ai} - x_A}$$

UMD

$$h_T = \int_{x_{A2}}^{x_{A1}} \frac{L}{k_L^o\, a\, \bar{\rho}_M} \frac{x_{BM}}{1 - x_A} \frac{dx_A}{x_{Ai} - x_A}$$

Const. H_L

$$h_T = H_L \int_{x_{A2}}^{x_{A1}} \frac{x_{BM}}{1 - x_A} \frac{dx_A}{x_{Ai} - x_A}$$

Dilute case

$$h_T = H_L \int_{x_{A2}}^{x_{A1}} \frac{dx_A}{x_{Ai} - x_A}$$

2-film theory overall liq.-film resistance

$$h_T = \int_{x_{A2}}^{x_{A1}} \frac{L}{K_{OL}^o\, a\, \bar{\rho}_M} \frac{(X_f^*)_A}{1 - t_A x_A} \frac{dx_A}{x_A^* - x_A}$$

UMD

$$h_T = \int_{x_{A2}}^{x_{A1}} \frac{L}{K_{OL}^o\, a\, \bar{\rho}_M} \frac{x_{BM}^*}{1 - x_A} \frac{dx_A}{x_A^* - x_A}$$

Const. H_{OL}

$$h_T = H_{OL} \int_{x_{A2}}^{x_{A1}} \frac{x_{BM}^*}{1 - x_A} \frac{dx_A}{x_A^* - x_A}$$

Dilute case

$$h_T = H_{OL} \int_{x_{A2}}^{x_{A1}} \frac{dx_A}{x_A^* - x_A}$$

y=mx* ; const. m

$$h_T = H_{OL} \frac{1}{1-A} \ln\left\{(1-A)\left(\frac{y_1 - m x_2}{y_1 - m x_1}\right) + A\right\}$$

$$h_T = H_{OL} \frac{x_{A1} - x_{A2}}{\left(x_A^* - x_A\right)_{LM}}$$

Rigorous procedure to calculate column height

Overall gas phase driving force

$$h_T = \int_{y_{A2}}^{y_{A1}} \frac{G}{K_{OG}^{o}\, a\, P} \, \frac{y_{BM}^{*}}{1 - y_A} \, \frac{dy_A}{y_A - y_A^{*}}$$

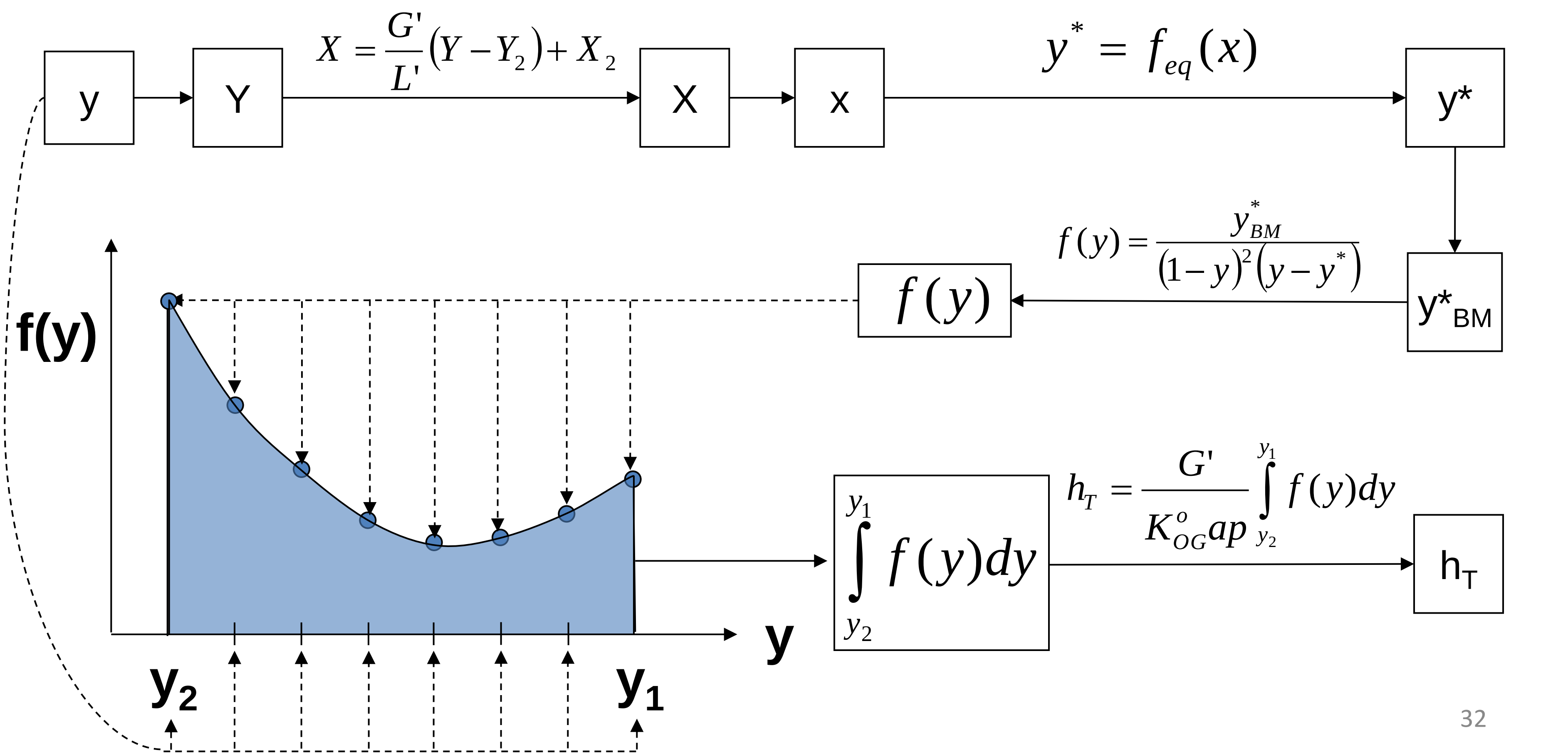
$$= \frac{G'}{K_{OG}^{o}\, a\, P} \int_{y_{A2}}^{y_{A1}} \frac{y_{BM}^{*}}{(1 - y_A)^2} \, \frac{dy_A}{y_A - y_A^{*}}$$

$$= \frac{G'}{K_{OG}^{o}\, a\, P} \int_{y_{A2}}^{y_{A1}} f(y_A)\, dy_A$$

Rigorous procedure to calculate column height

Overall gas phase driving force

- Chose values of y between y_2 and y_1
- For each value of y (including y_2 and y_1), calculate f(y)
- Integrate f(y) numerically between y_2 and y_1



Rigorous procedure to calculate column height

Individual gas phase driving force

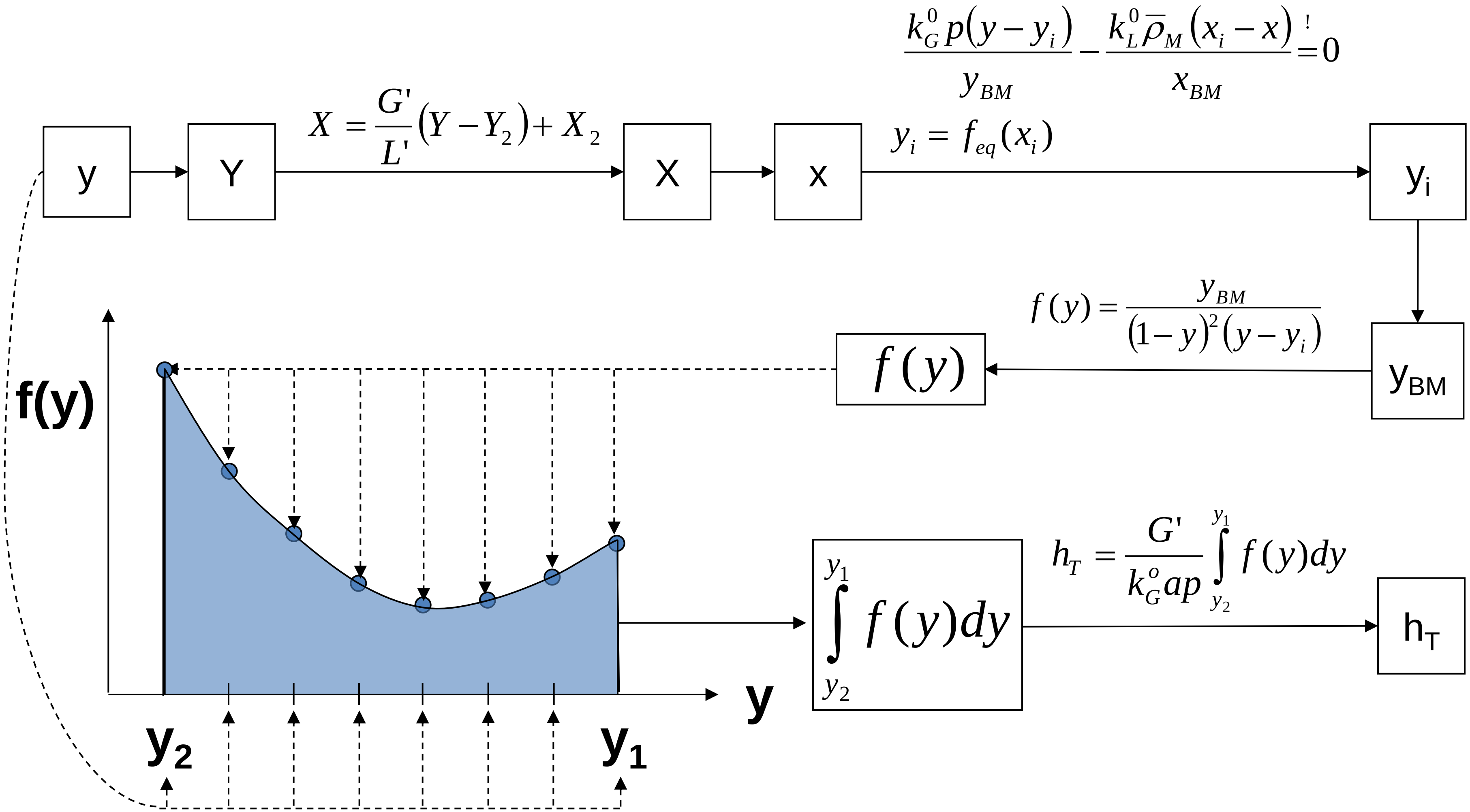
$$h_T = \int_{y_{A2}}^{y_{A1}} \frac{G}{k_G^o\, a\, P} \frac{y_{BM}}{1-y_A} \frac{dy_A}{y_A - y_{A,i}}$$

$$= \frac{G'}{k_G^o\, a\, P} \int_{y_{A2}}^{y_{A1}} \frac{y_{BM}}{\left(1-y_A\right)^2} \frac{dy_A}{y_A - y_{A,i}}$$

$$= \frac{G'}{k_G^o\, a\, P} \int_{y_{A2}}^{y_{A1}} f(y_A)\, dy_A$$

Rigorous procedure to calculate column height

Individual gas phase driving force



Procedure to calculate column performance

Individual gas phase driving force

known

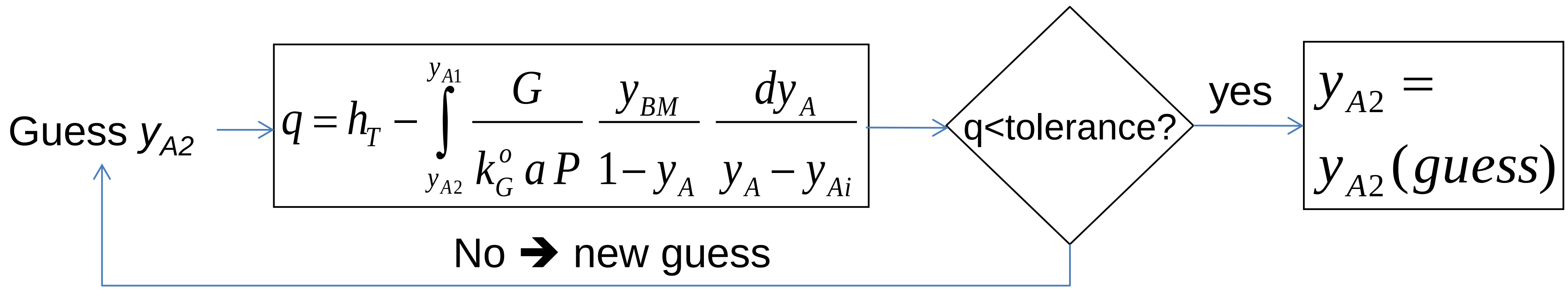
$$h_T = \int_{y_{A2}}^{y_{A1}} \frac{G}{k_G^o\, a\, P} \frac{y_{BM}}{1 - y_A} \frac{dy_A}{y_A - y_{Ai}}$$

unknown

$$\text{Procedure : Change } y_{A2} \text{ until } h_T = \int_{y_{A2}}^{y_{A1}} \frac{G}{k_G^o\, a\, P} \frac{y_{BM}}{1 - y_A} \frac{dy_A}{y_A - y_{Ai}}$$

Procedure to calculate column performance

Individual gas phase driving force



$$\text{where } Y_A = Y_{A2} + \frac{L'}{G'}\left(X_A - X_{A2}\right) \text{ and } \; y_{BM} = \frac{\left(1 - y_A\right) - \left(1 - y_{Ai}\right)}{\ln\left(\dfrac{1 - y_A}{1 - y_{Ai}}\right)}$$

Integral can be solved numerically as described in previous slides

How to measure H_G (part 1)

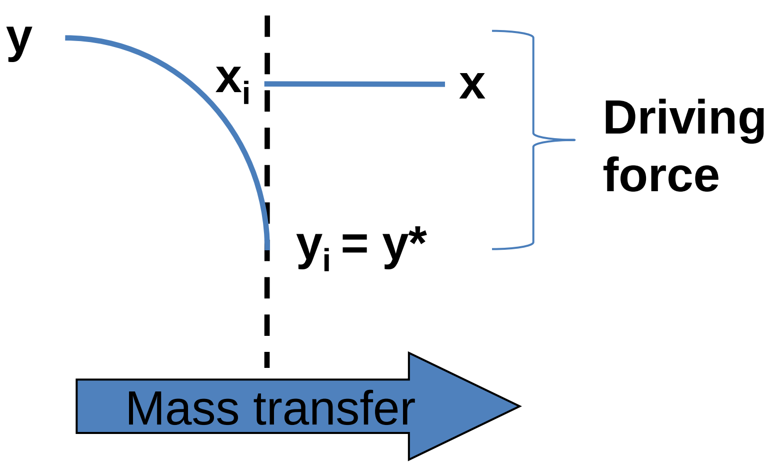
Run experiments in absorber under conditions where only the gas film controls mass transfer:

- Absorption or desorption of very soluble gas ➔ m ↓
- Or evaporation of pure liquid

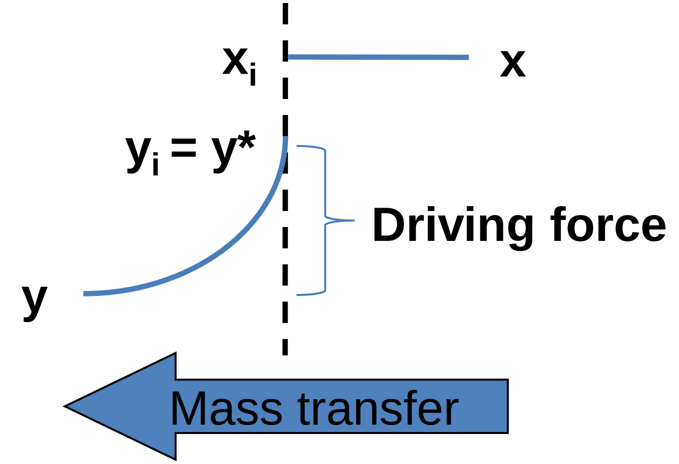
$$\rightarrow \boxed{H_{OG} = H_G + \frac{H_L mG}{L} = H_G}$$

<u>**SOME CONCENTRATION PROFILES:**</u>

<u>**Absorption low m:**</u>



<u>**Evaporation of pure liquid:**</u>

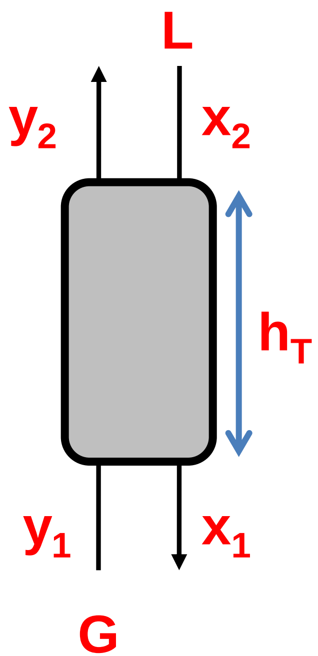


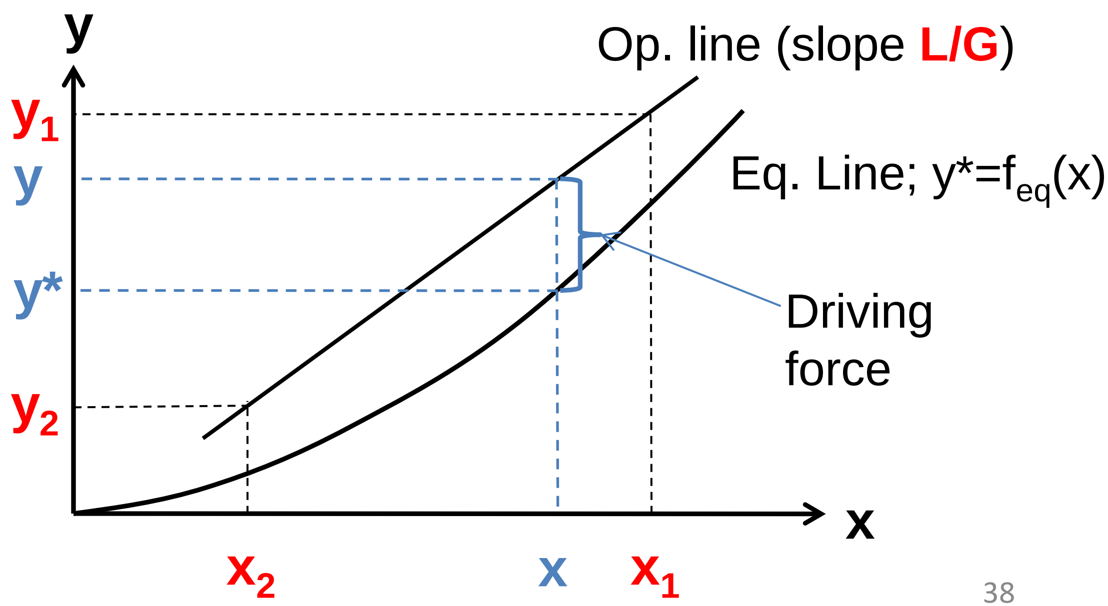
How to measure H_G (part 2)

$$H_G = H_{OG} = \frac{h_T}{N_{OG}}$$

$$\text{where} \quad N_{OG} = \int_{y_2}^{y_1} \frac{dy}{y - y^*} = \int_{y_2}^{y_1} \frac{dy}{y - f_{eq}(x)}$$

- Measure column height.
- Measure flowrates and concentrations at column inlet and outlet.
- Integrate inverse of overall driving force between y_1 and y_2 to obtain $N_{OG,}$ but if eq. line in straight use Colburn eq. or mean driving force eq.





How to measure H_L (part 1)

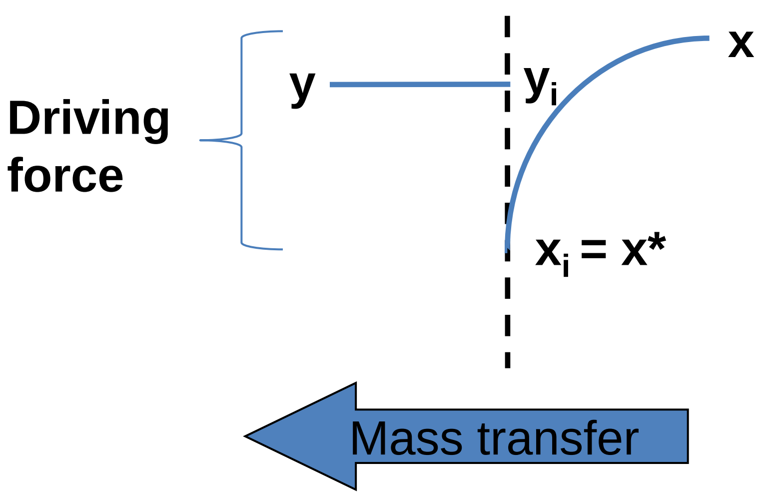
Run experiments in absorber under conditions where only the liquid film controls mass transfer:

- Absorption or desorption of low solubility gas ➔ m ↑
- Or absorption of pure gas

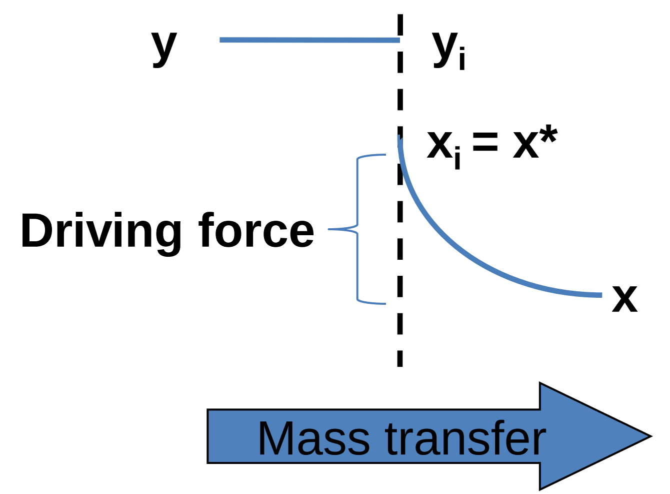
$$\rightarrow \quad \boxed{H_{OL} = H_L + \frac{H_G L}{mG} = H_L}$$

CONCENTRATION PROFILES

Desorption low solubility gas:



Absorption pure or low solubility gas:

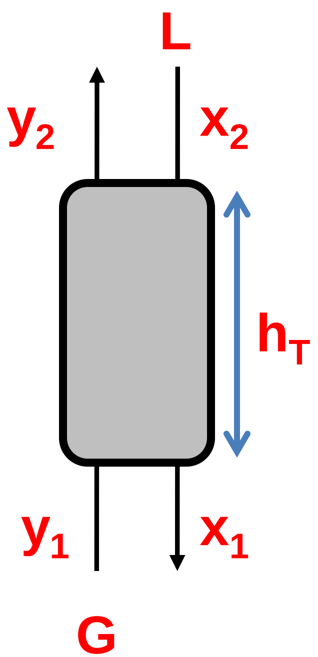


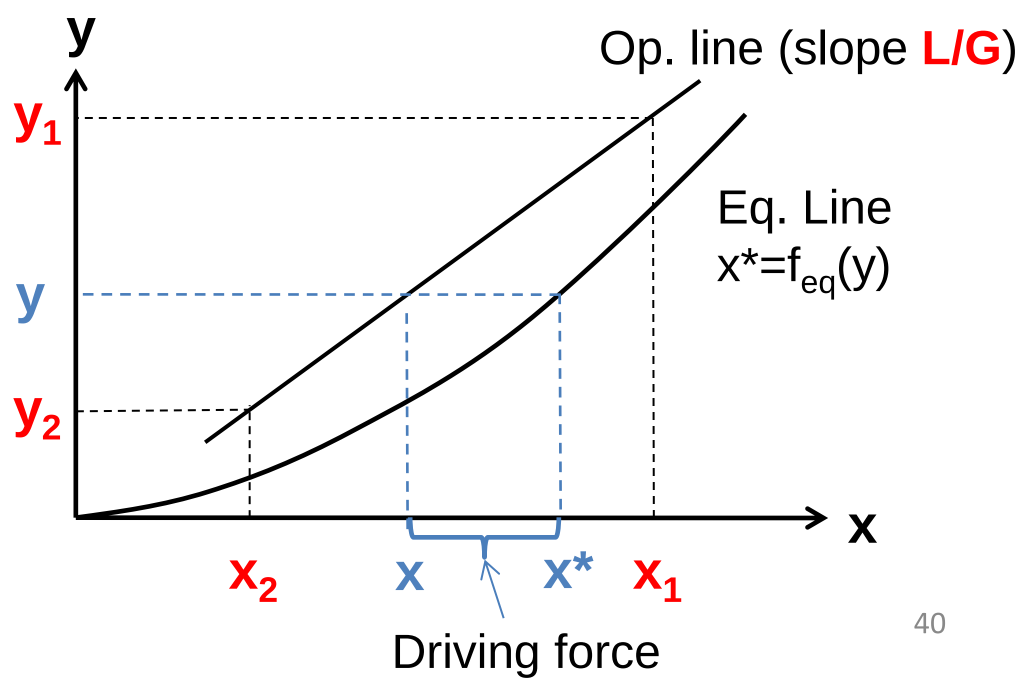
How to measure H_L (part 2)

$$H_L = H_{OL} = \frac{h_T}{N_{OL}}$$

$$\text{where} \quad N_{OL} = \int_{x_2}^{x_1} \frac{dx}{x^* - x} = \int_{x_2}^{x_1} \frac{dx}{f_{eq}(y) - x}$$

- Measure column height.
- Measure flowrates and concentrations at column inlet and outlet.
- Integrate inverse of overall driving force between x_1 and x_2 to obtain N_{OL} but if eq. line in straight use Colburn eq. or mean driving force eq.





Short-Cut method for concentrated cases with non-linear equilibrium line*

Approach:

Integrated following equation with various non-linear equilibrium lines and varying flowrate ratios (L/G) for hundreds of hypothetical cases.

Calculated the effective values of m ($\overline{m}$) and L/G (R_{av}) to use in Colburn's equation in order to obtain the same result.

$$N_{OG} = \int_{y_{A2}}^{y_{A1}} \frac{dy_A}{y_A - y_A^*}$$

**C. R. Wilke and U. von Stockar, Absorption, in Encyclopedia of Chemical Technology, Vol. 1, Kirk-Othmer (Eds.), Wiley, New York, 1978.*

Short-Cut method for concentrated cases with non-linear equilibrium line

$$N_{OG}=\frac{\ln\left\{\left(1-\frac{\overline{m}}{R_{\text{av}}}\right)\left(\frac{y_1-\overline{m}x_2}{y_2-\overline{m}x_2}\right)+\frac{\overline{m}}{R_{\text{av}}}\right\}}{1-\frac{\overline{m}}{R_{\text{av}}}}+0.5\ln\frac{1-y_2}{1-y_1}$$

where $\overline{m}$ and R_{av} are obtained from correlations

$$\overline{m}=f\left(m_2,m_c,f,y_1,y_2\right)$$

$$R_{\text{av}}=f\left(R_1,R_2,f,y_1,y_2\right)$$

$$\text{where } f=\frac{y_1^*}{y_1};R_1=\frac{L_1}{G_1};R_2=\frac{L_2}{G_2}$$

$$H_{OG}=H_G+H_L\frac{\overline{m}}{R_{\text{av}}}$$

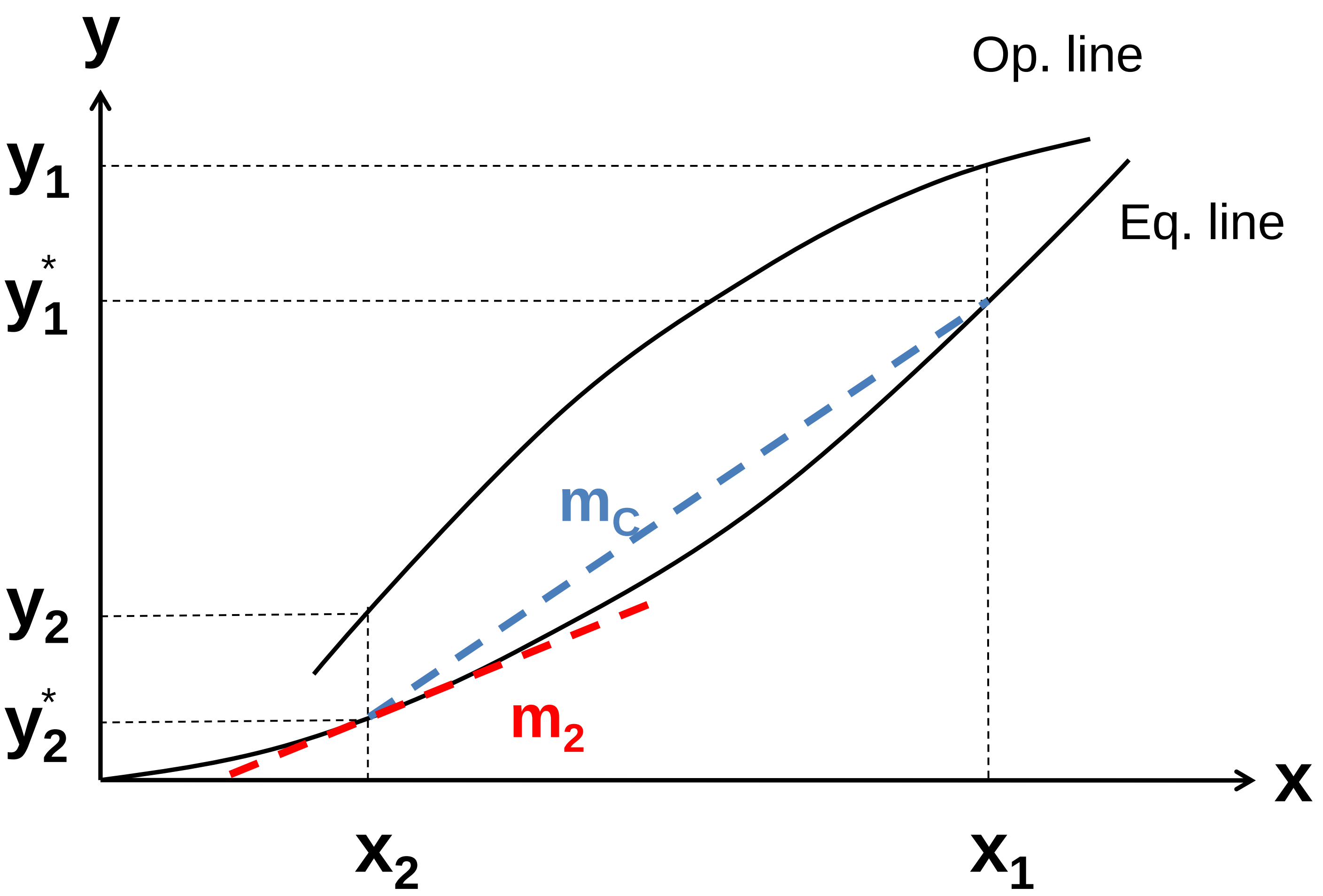
Corrective term due to fact that real equation is:

$$N_{OG}=\int_{y_{A2}}^{y_{A1}}\frac{y_{BM}^*}{1-y_A}\frac{dy_A}{y_A-y_A^*}$$

Correlations in charts 5.8a, 5.8b and 5.9

Short-Cut Method

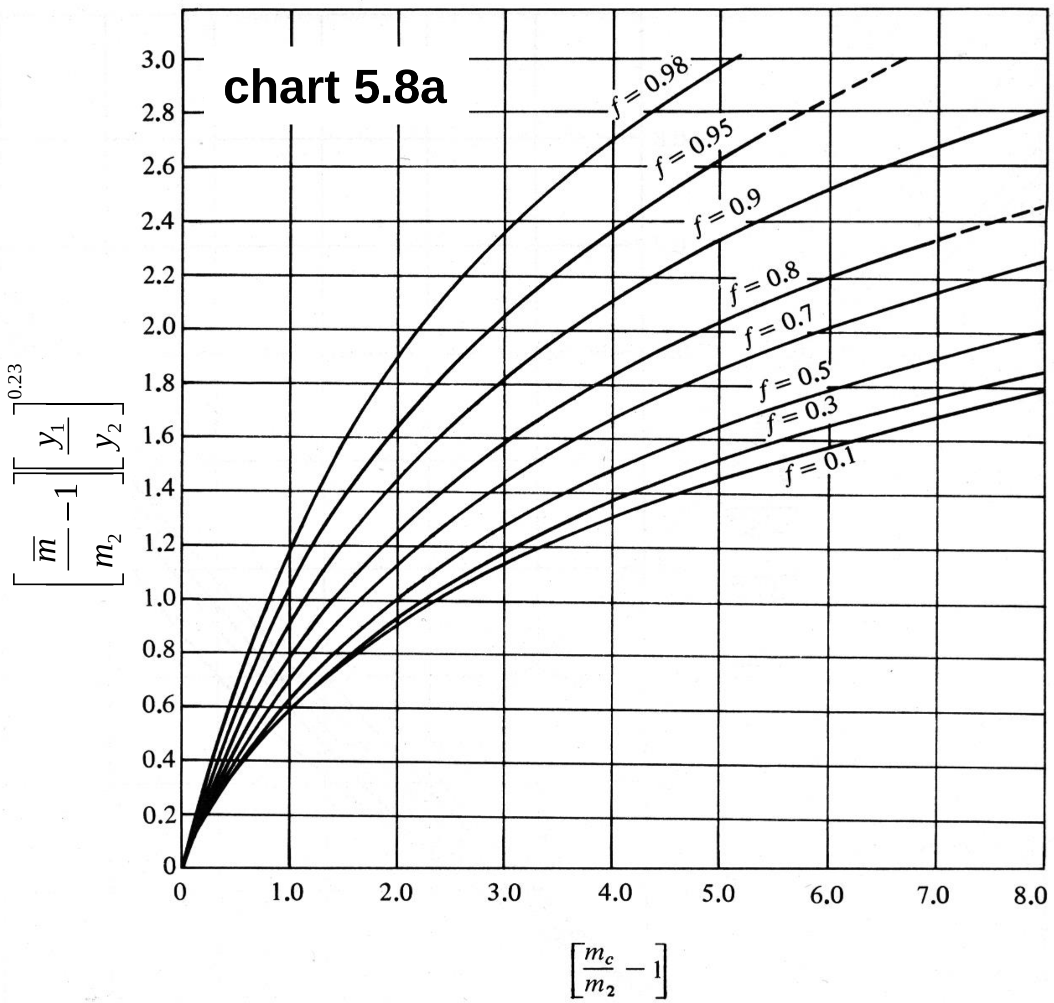
Equilibrium line with increasing slope



Correlation in chart 5.8a

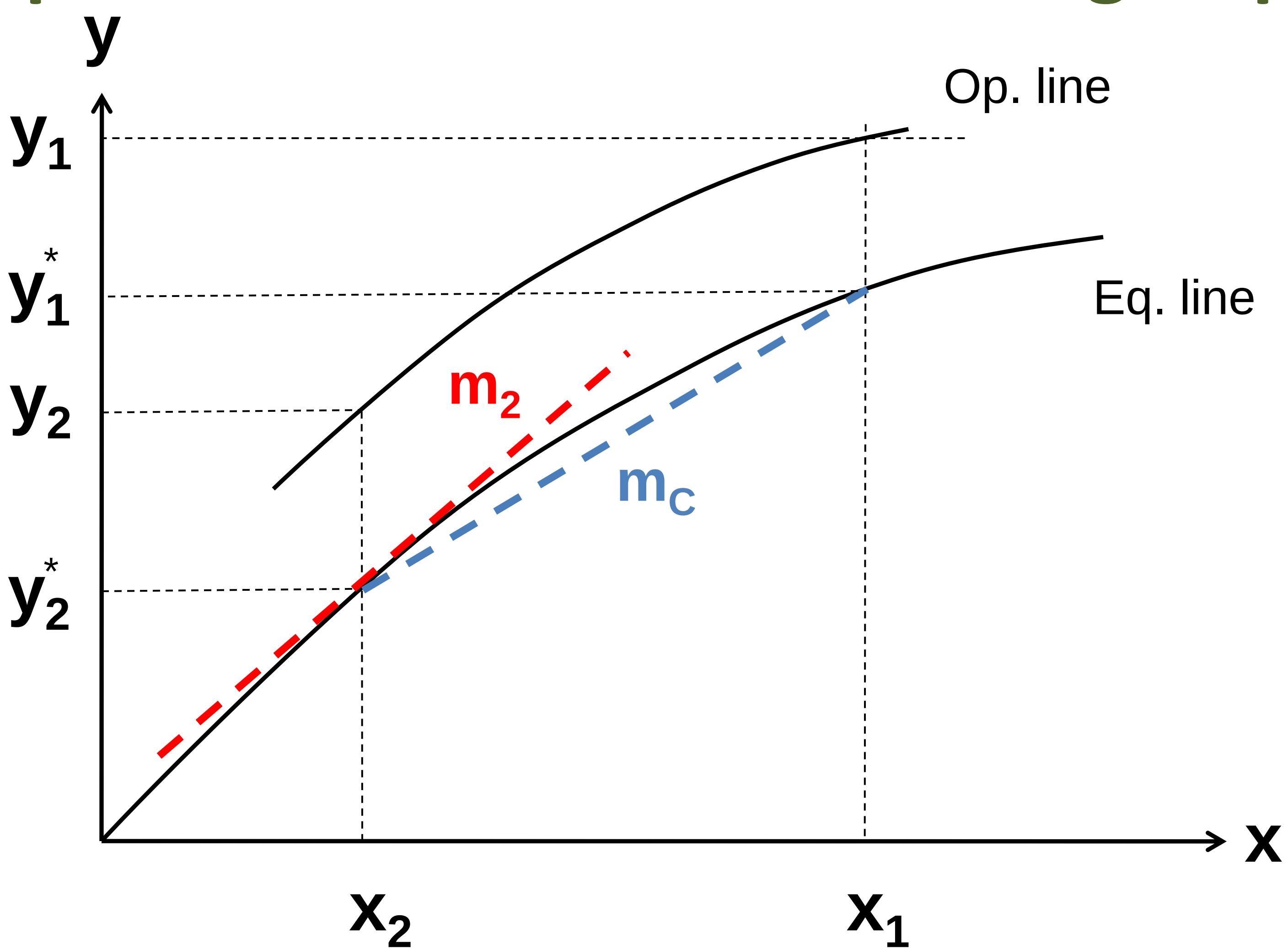
Short-Cut method for concentrated cases with non-linear equilibrium line

Effective slope for equilibrium lines with increasing slope



Short-Cut Method

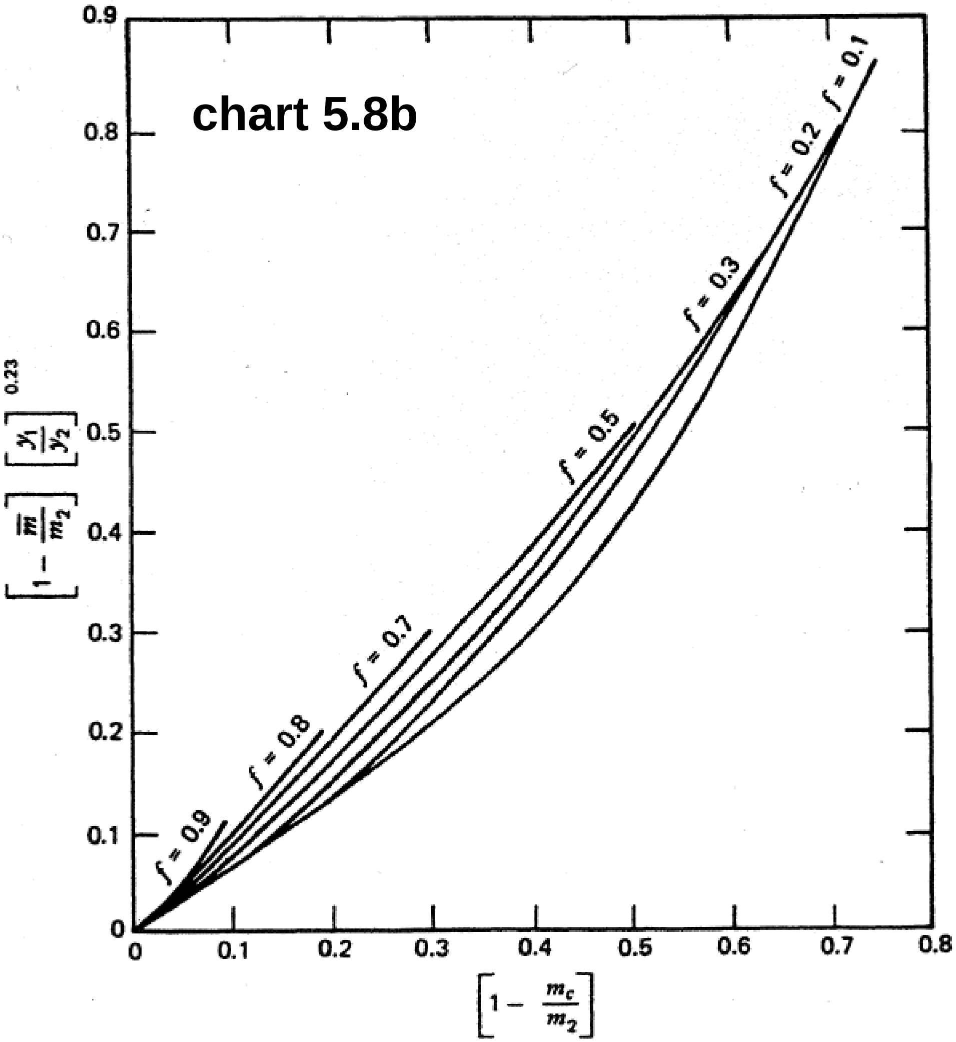
Equilibrium line with decreasing slope



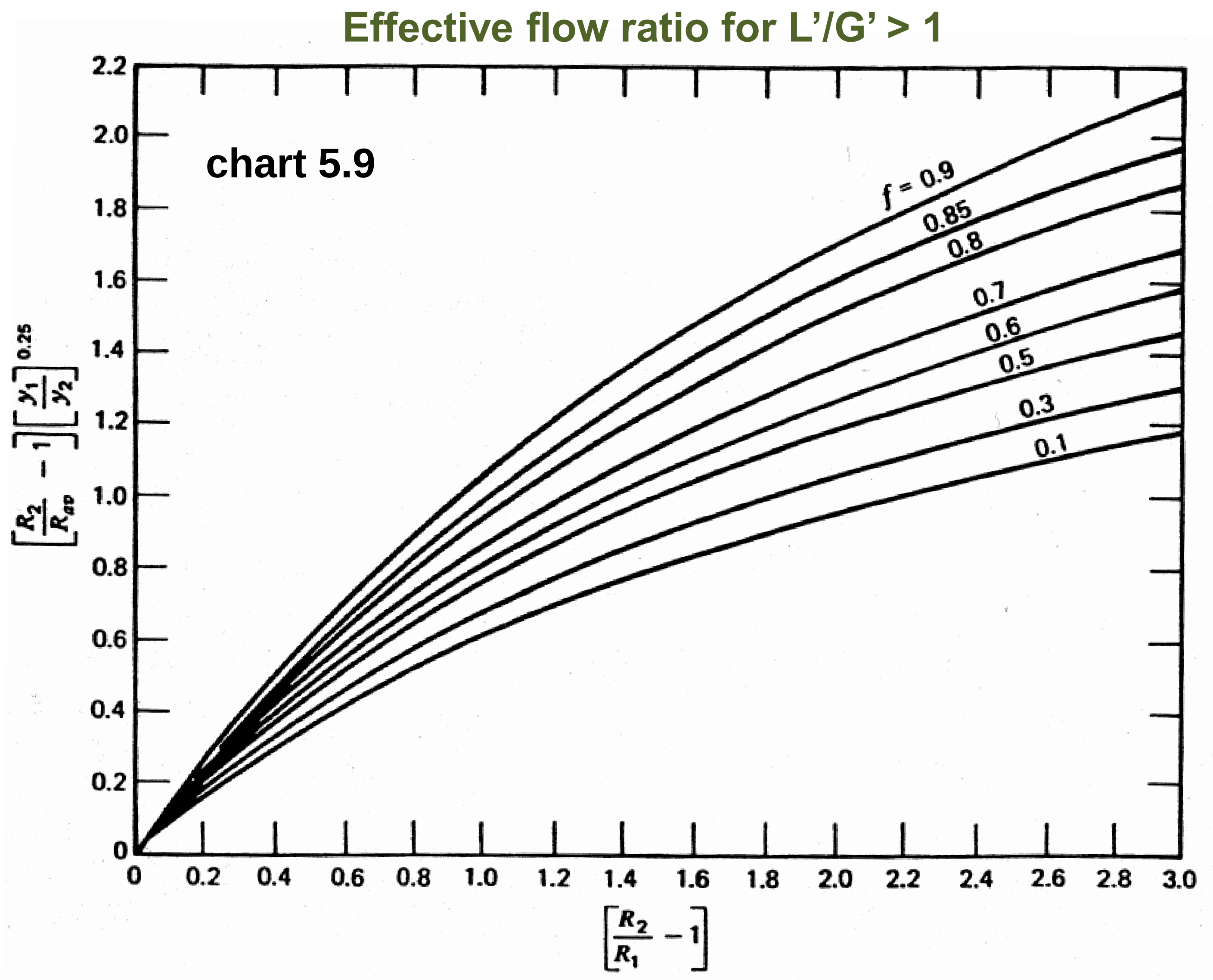
Correlation in chart 5.8b

Short-Cut method for concentrated cases with non-linear equilibrium line

Effective slope for equilibrium lines with decreasing slope



Short-Cut method for concentrated cases with non-linear equilibrium line



Eq.-stage *vs* mass transfer approaches*

Absorption: high solubility cases

- **Example: absorption of acidic solute in basic solution → zero acid solute volatility ($y^* \sim 0$)**
- **In this extreme case, eq.-stage approach:**
  - Predicts 100% absorption with 1 stage
  - Predicts slightly less than 1 eq. stage
  - Creates illusion of easy absorption and short column (neglects decrease in driving force)
  - Is ineffective for design

**K. Graf, Chemical Engineering, "Determining packing height with accuracy", 10/2011, pp 55-62.*

Eq.-stage *vs* mass transfer approaches

Absorption: high solubility cases

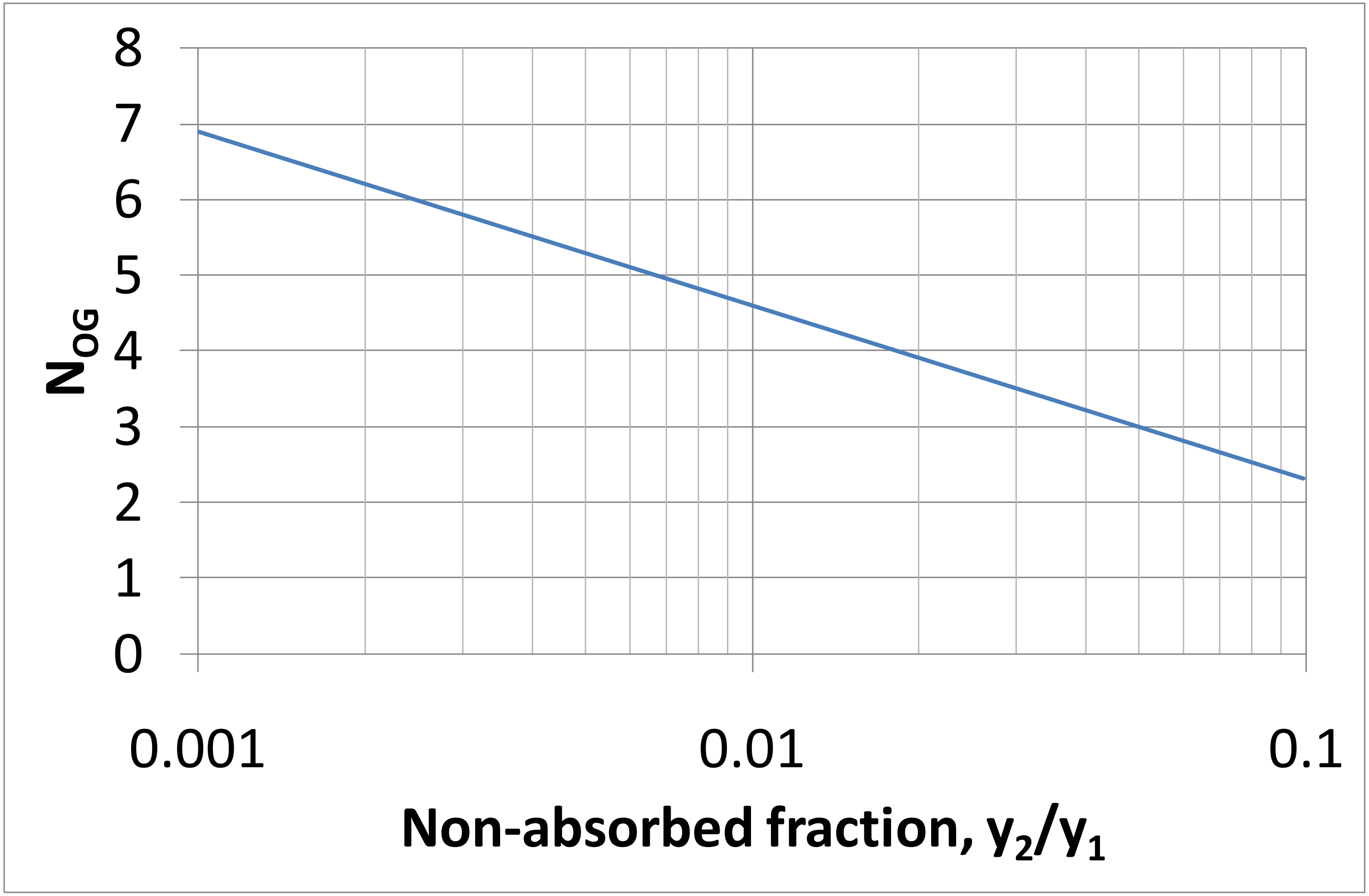
- **Mass-transfer approach must be used:**

$$\boxed{\begin{aligned} &N_{OG} = \int_{y_2}^{y_1} \frac{dy}{y - y^*} = \int_{y_2}^{y_1} \frac{dy}{y} = \ln\left(\frac{y_1}{y_2}\right) \\ &y_2 = y_1 \exp\left(-N_{OG}\right) \end{aligned}}$$

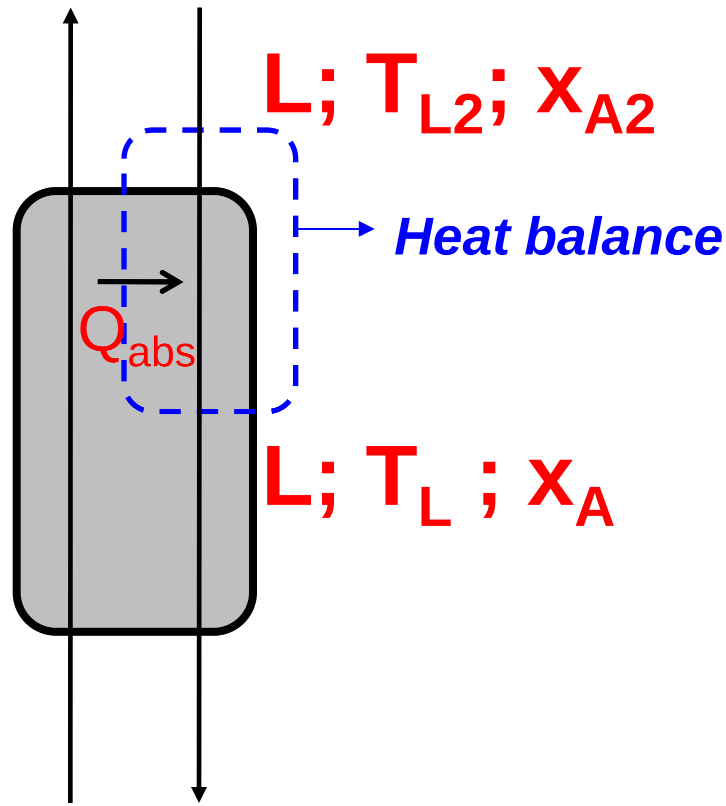
- **N_{OG}>NTS! (next slide)**

Eq.-stage *vs* mass transfer approaches

Absorption: high solubility cases



Adiabatic Absorption

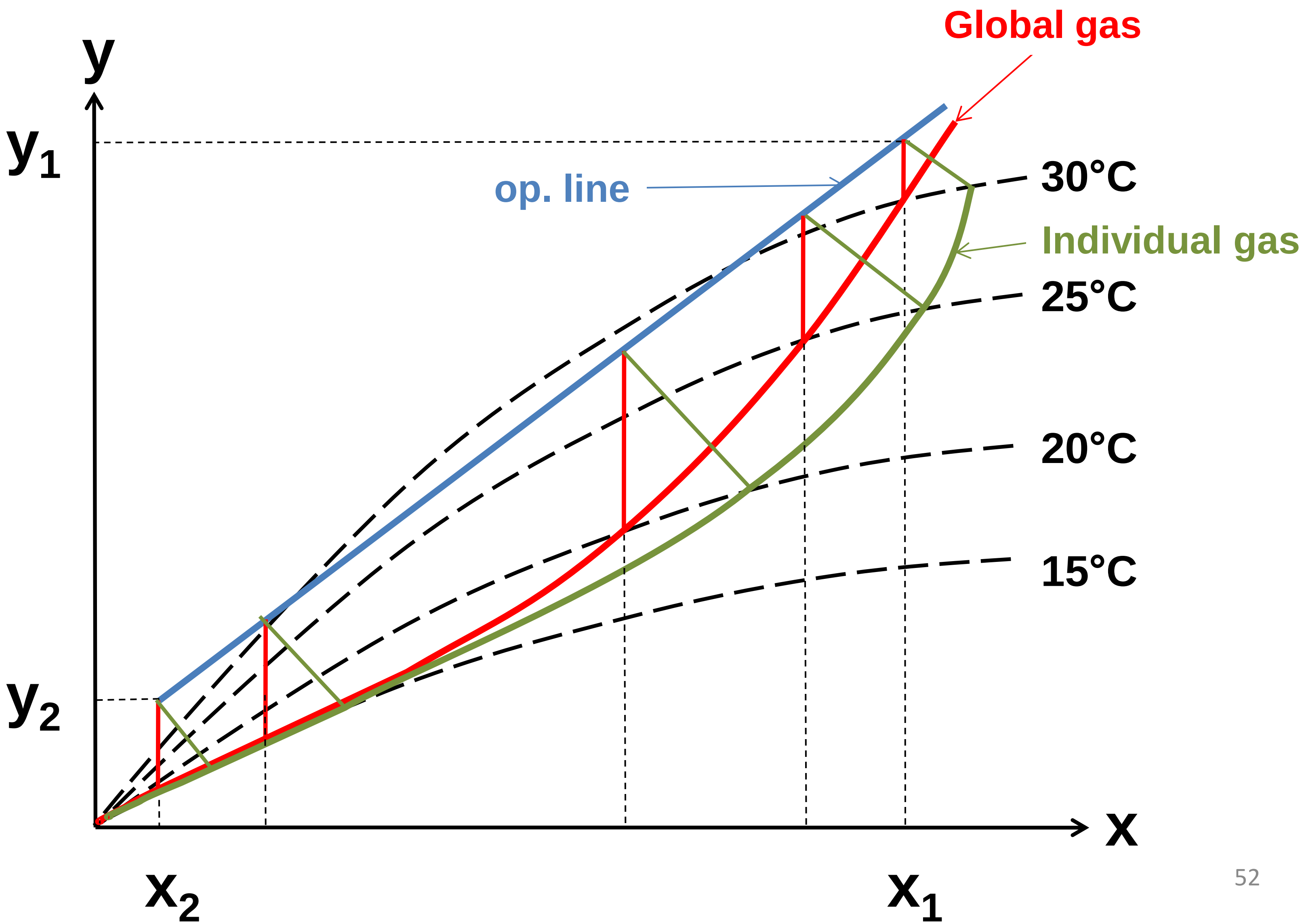


$$L\,S\,\bar{c}_{PL}\left(T_L - T_{L2}\right) = L\,S\,\Delta_{abs}H\left(x_A - x_{A2}\right)$$

$$\Rightarrow T_L = T_{L2} + \frac{\Delta_{abs}H}{\bar{c}_{PL}}\left(x_A - x_{A2}\right)$$

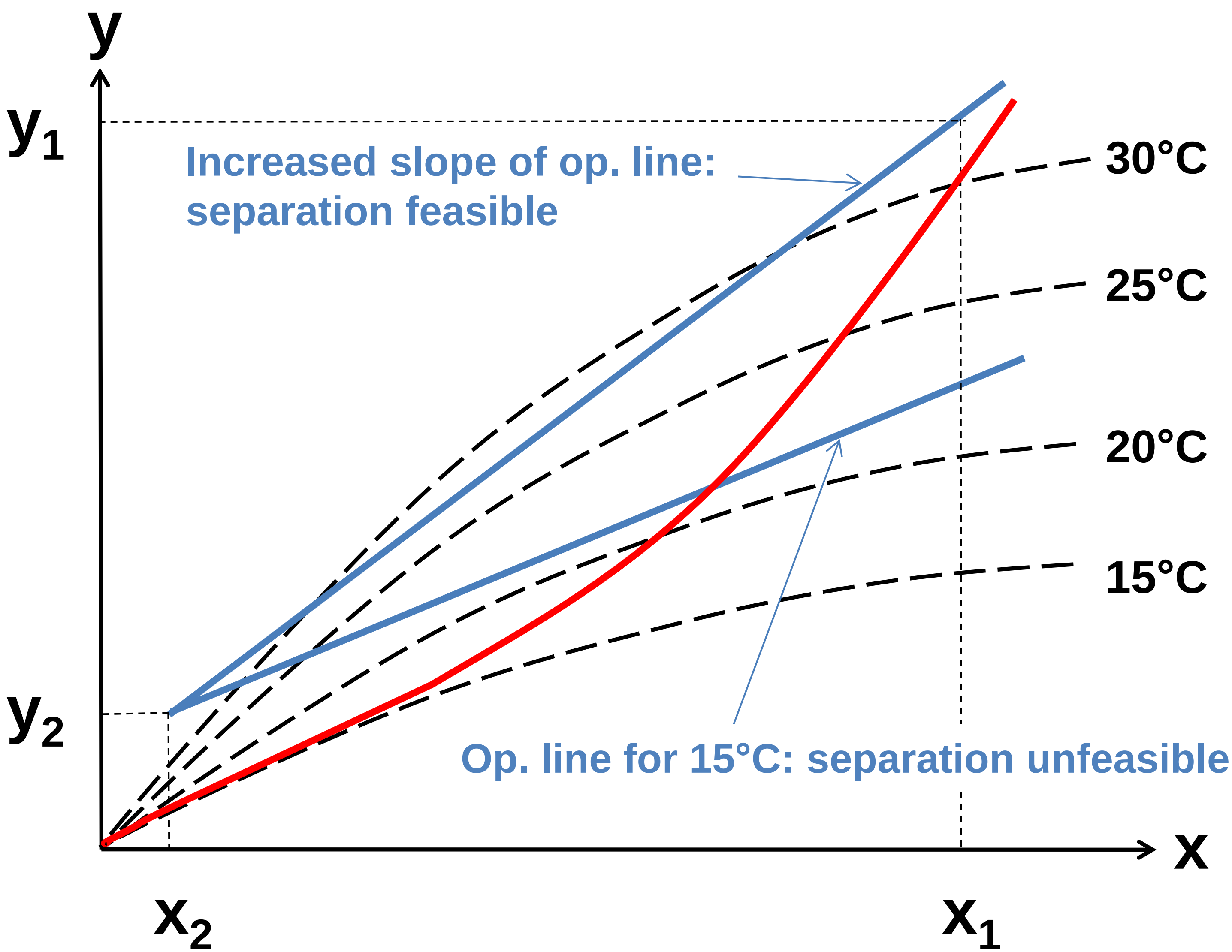
Adiabatic Absorption

Effective equilibrium line



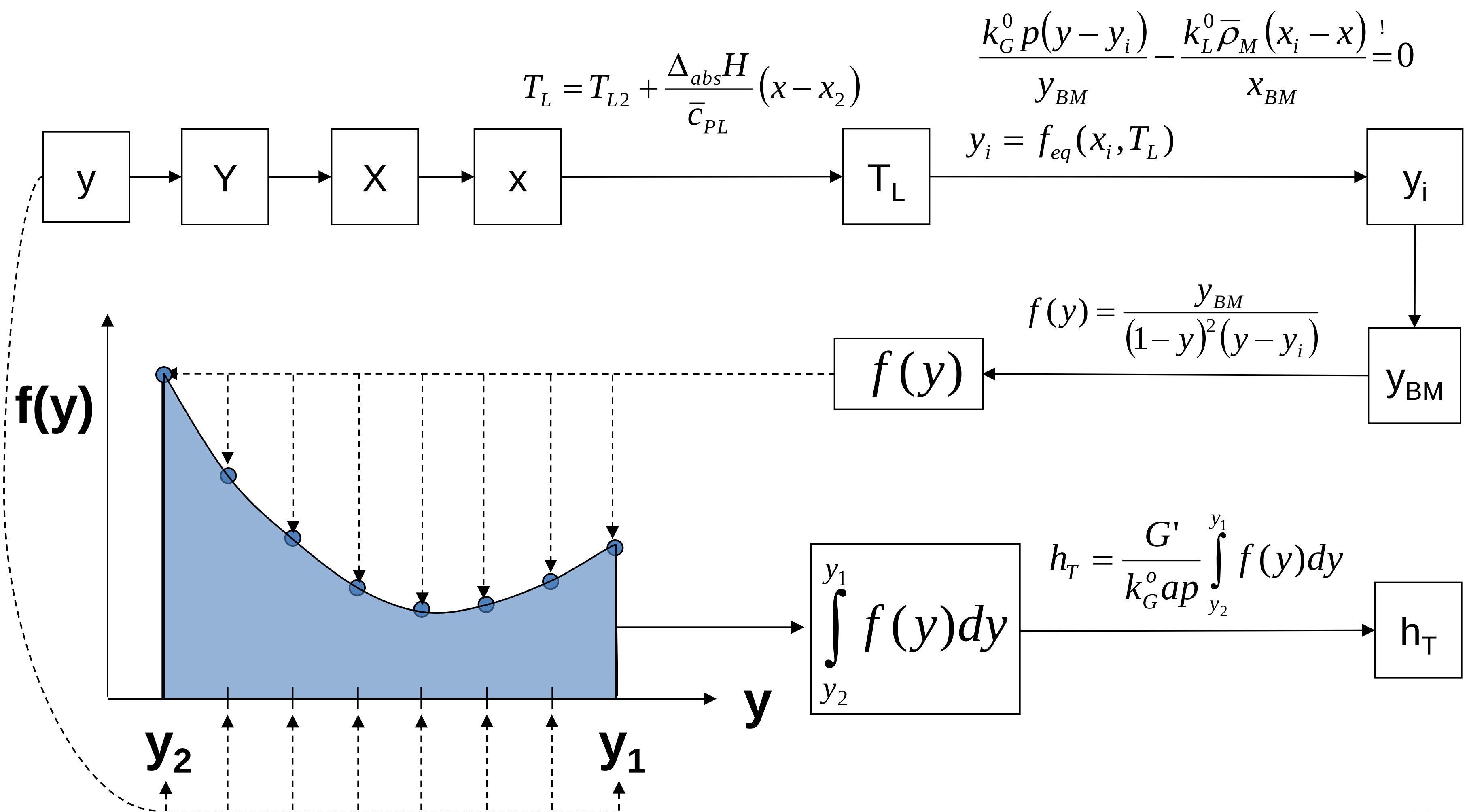
Adiabatic Absorption

Effective equilibrium line



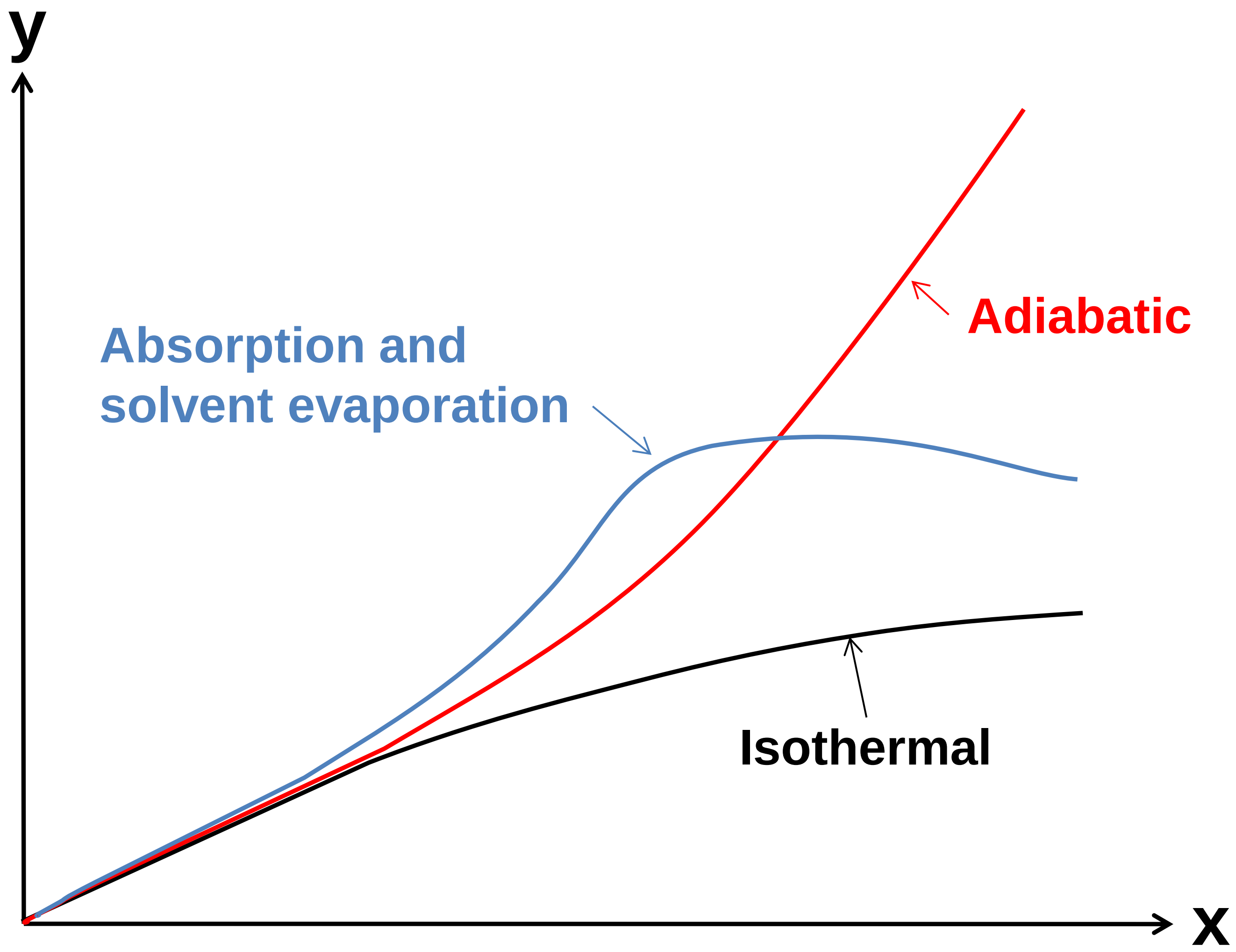
Procedure to calculate column height

Individual gas phase driving force, adiabatic absorption



Effective equilibrium lines

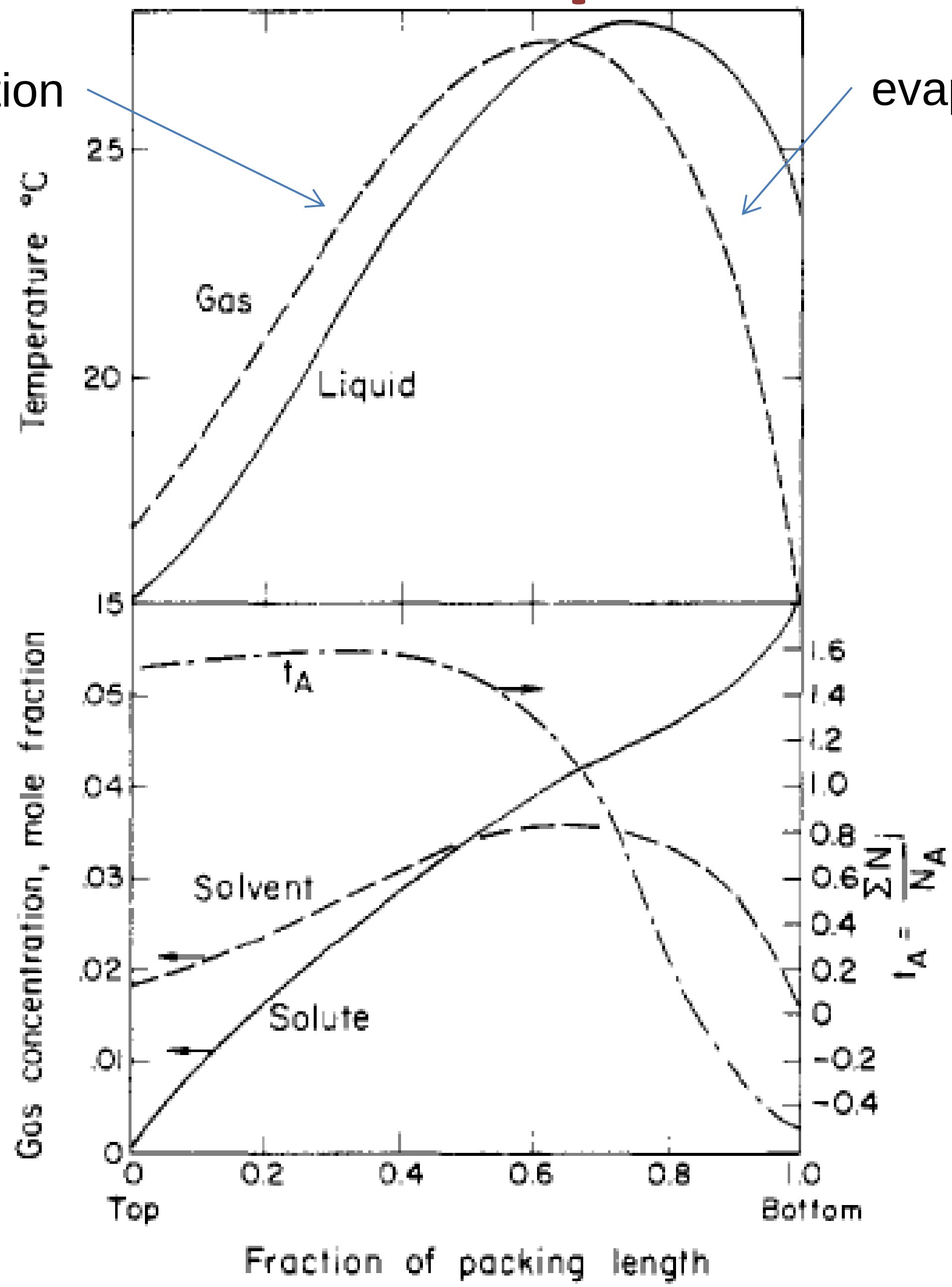
Heat and solvent evaporation effects



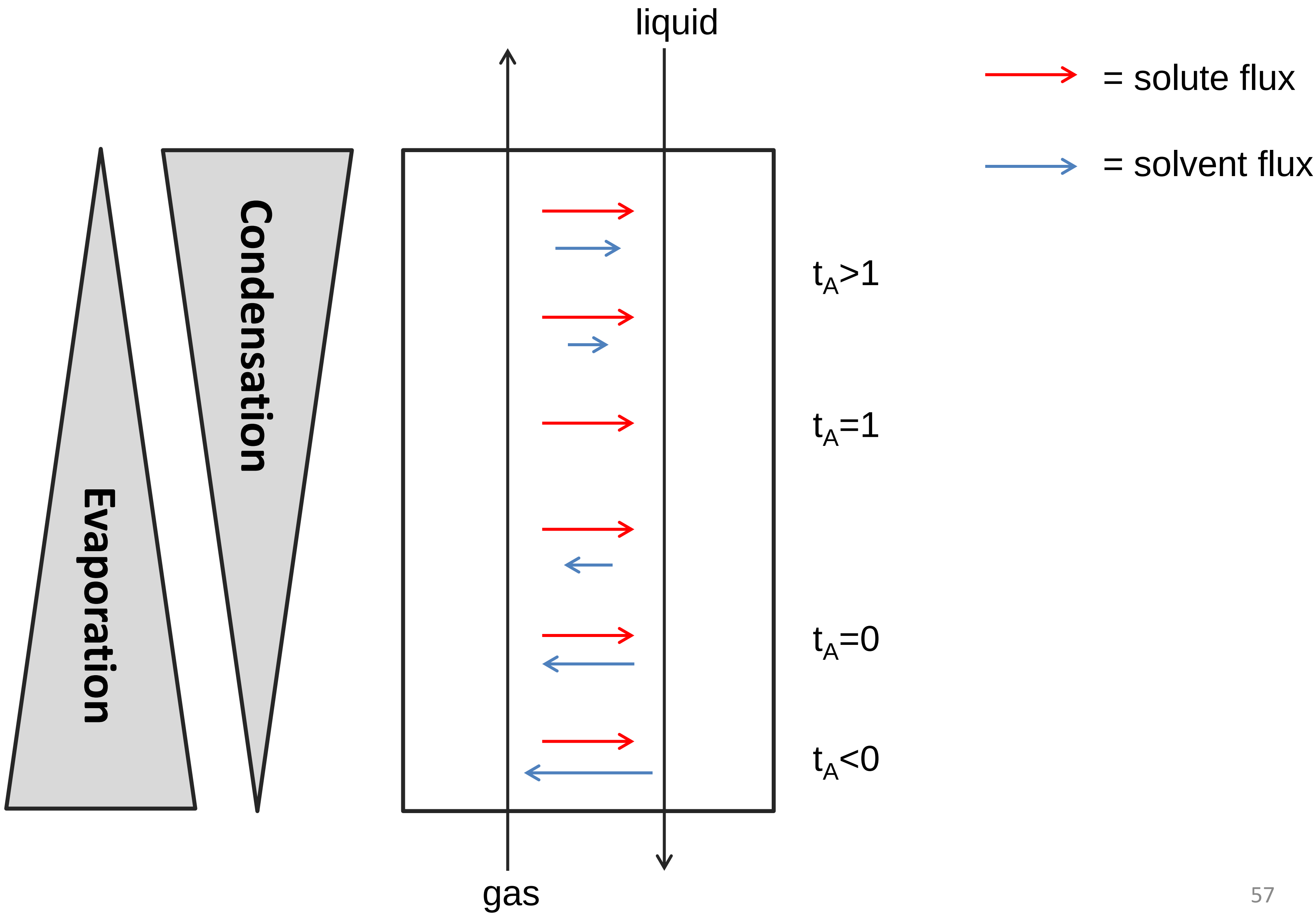
Heat and solvent evaporation effects

condensation

evaporation



Heat and solvent evaporation effects



Shortcut Method for Estimating Equilibrium Line of Non-Isothermal Absorbers

$$T_L = T_{L,2} + (T_{L,1} - T_{L,2}) X_N + 74.34 (X_N^{1.074} - X_N^{1.114}) \Delta T_{max}$$

From correlation in article

$$X_N = \frac{x_A - x_{A,2}}{x_{A,1} - x_{A,2}}$$

$$T_{G,2} = T_{L,2} + \left(\frac{dT_L}{dx_A}\right)_2 \left(\frac{G_2}{L_2}\right)\left(\frac{H_{G,Q}}{H_{OG,A}}\right)\left(y_{A,2} - y^*_{A,2}\right)$$

$$\left(\frac{dT_L}{dx_A}\right)_2 = \frac{L_2 H_{OS} - G_2 H_v m_{B,2}}{L_2 C_{pL,2} - G_2 C_{pG,2} - H_v (1 - x_{A,2}) \left(\frac{dm_B}{dT_L}\right)_2}$$

Von Stockar, U. and Wilke, C.R., Ind. Eng. Chem. Fundam., Vol. 16, No. 1, 1977 (94-103)

Shortcut Method for Estimating Equilibrium Line of Non-Isothermal Absorbers

Definitions

$$H_{G,Q} = \frac{G\,C_{pG}}{h_G\,a} = Gas\ phase\ height\ of\ a\ heat\ transfer\ unit$$

$$H_{OS} \quad Integral\ heat\ of\ solution\ for\ solute$$

$$H_{\mathrm{v}} \quad Latent\ heat\ for\ pure\ solvent$$

$$C_{pL} \quad Mean\ molar\ heat\ capacity\ of\ liquid$$

$$C_{pG} \quad Mean\ molar\ heat\ capacity\ of\ gas$$

$$m_B \quad Solvent\ "solubility" = \frac{y_B^*}{x_B}$$