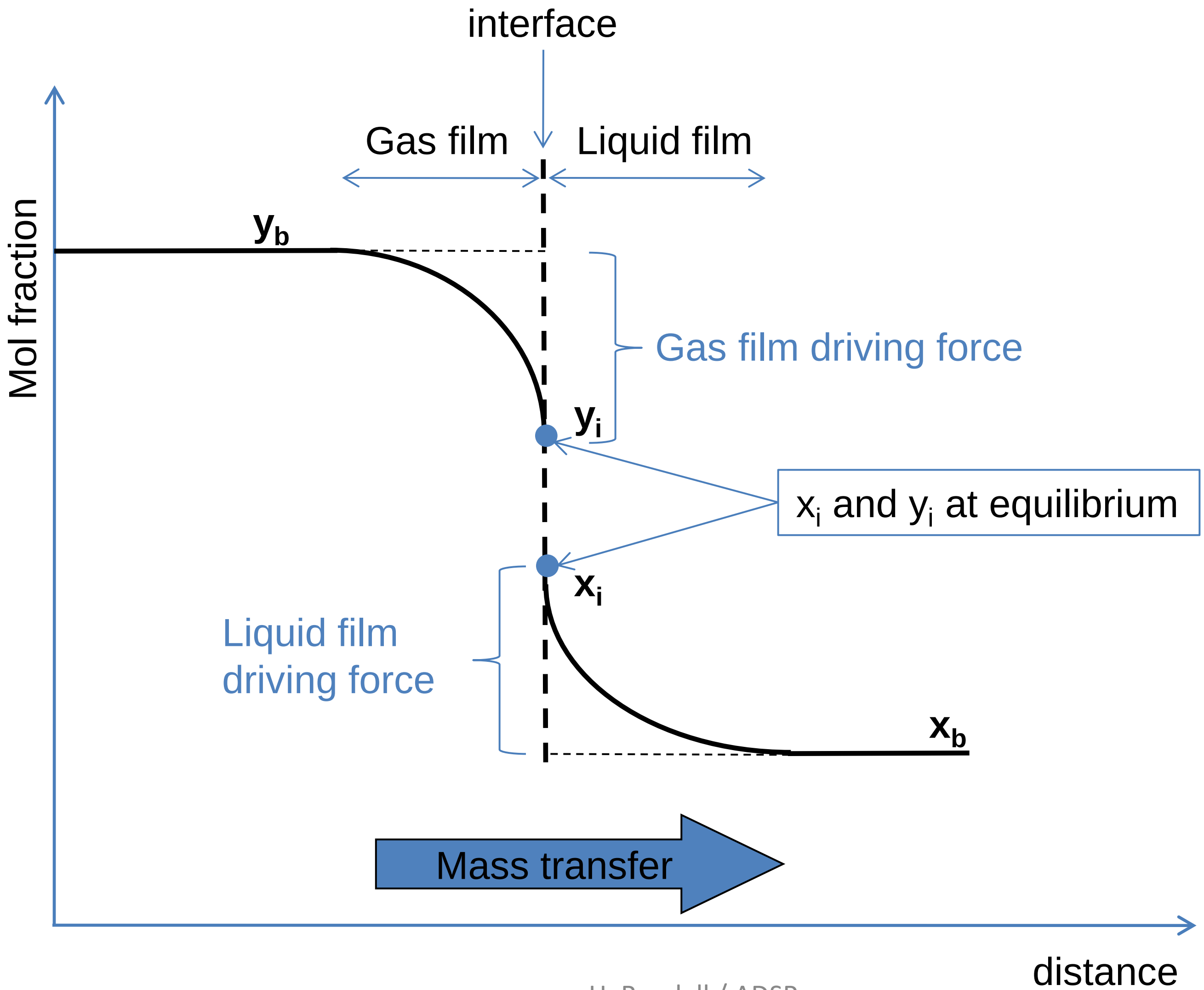
Two-Film Theory (Whitman)

- Two resistances in series (two stagnant films in which molecular diffusion takes place)
- Interfacial concentrations at equilibrium (assume no interfacial resistance to mass transfer)

Two-film theory



Two-film theory

Numerical solution

Flux in gas film: $N_A = k_G p(y_b - y_i)$

Flux in liquid film: $N_A = k_L \bar{\rho}_M (x_i - x_b)$

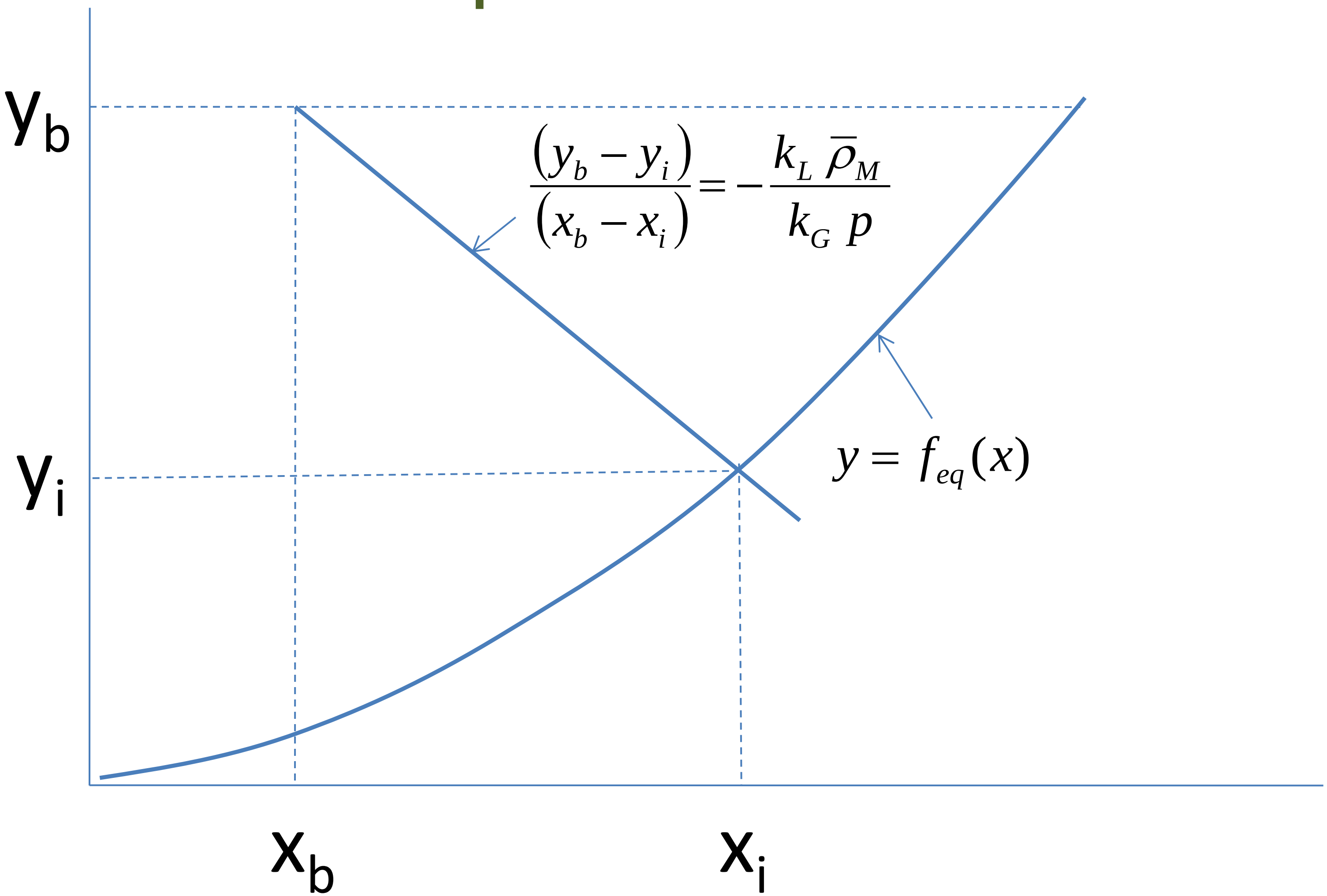
Equilibrium line: $y_i = f_{eq}(x_i)$

3 equations
3 unknowns (N_A, x_i, y_i)

Where $$k_G = \frac{k_G^0}{(Y_f)_A} \; ; \; k_L = \frac{k_L^0}{(X_f)_A}$$

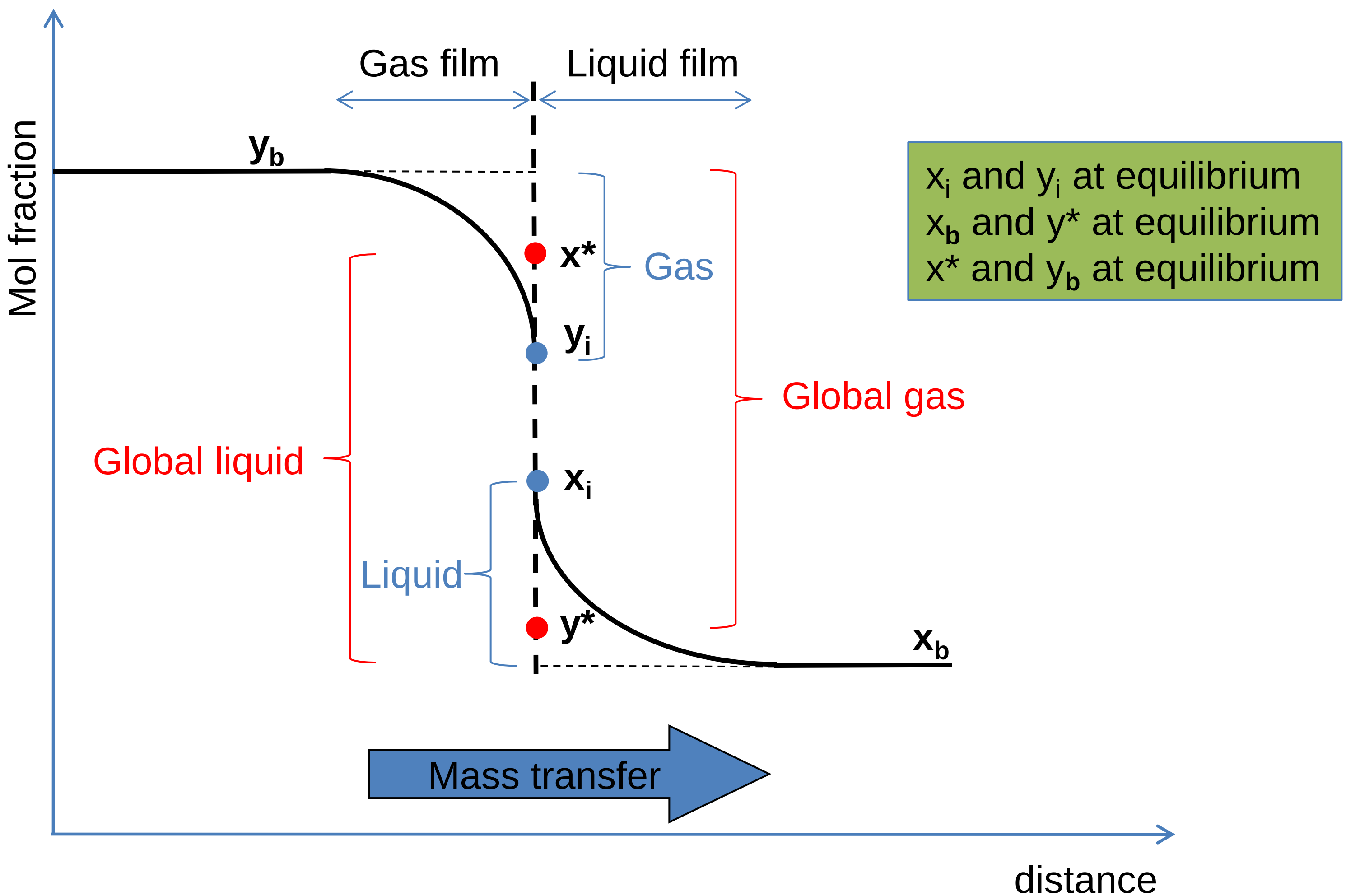
Two-film theory

Graphical solution



Two-film theory

Global driving forces



Two-film theory

Global driving forces, linear equilibrium relationship (y=mx)

$$y^* = m\,x_b \;\; ; \;\; y_b = m\,x^*$$

Flux in overall gas film:

$$N_A = K_{OG}\,p\left(y_b - y^*\right) = K_{OG}\,p\left(y_b - m\,x_b\right)$$

Flux in overall liquid film:

$$N_A = K_{OL}\bar{\rho}_M\left(x^* - x_b\right) = K_{OL}\bar{\rho}_M\left(\frac{y_b}{m} - x_b\right)$$

Overall mass transfer coefficients:

$$\frac{1}{K_{OG}} = \frac{1}{k_G} + \frac{m\,p}{k_L\,\bar{\rho}_M}$$

$$\frac{1}{K_{OL}} = \frac{1}{k_L} + \frac{\bar{\rho}_M}{k_G\,m\,p}$$

Valid only if linear equilibrium relationship!

Two-film theory

$$\boxed{K_{OG} = \frac{K^0_{OG}}{(Y^*_f)_A} \;;\; K_{OL} = \frac{K^0_{OL}}{(X^*_f)_A}}$$

$$\boxed{\left(Y^*_f\right)_A = \frac{\left(1 - t_A y_b\right) - \left(1 - t_A y^*\right)}{\ln\left(\dfrac{1 - t_A y_b}{1 - t_A y^*}\right)}}$$

$$\boxed{\left(X^*_f\right)_A = \frac{\left(1 - t_A x_b\right) - \left(1 - t_A x^*\right)}{\ln\left(\dfrac{1 - t_A x_b}{1 - t_A x^*}\right)}}$$

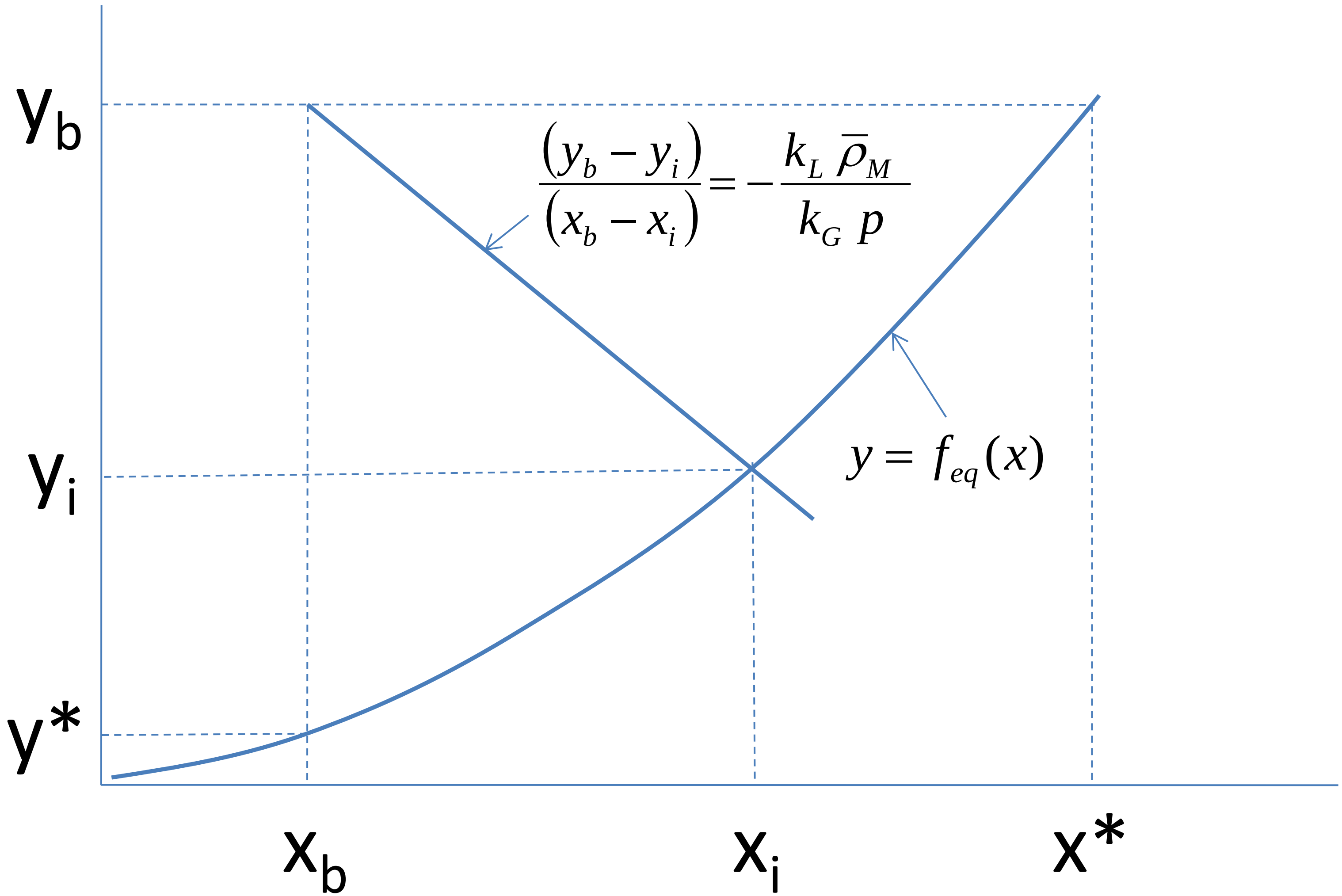
Two-film theory

$$k_G = \frac{k_G^0}{(Y_f)_A} \; ; \; k_L = \frac{k_L^0}{(X_f)_A}$$

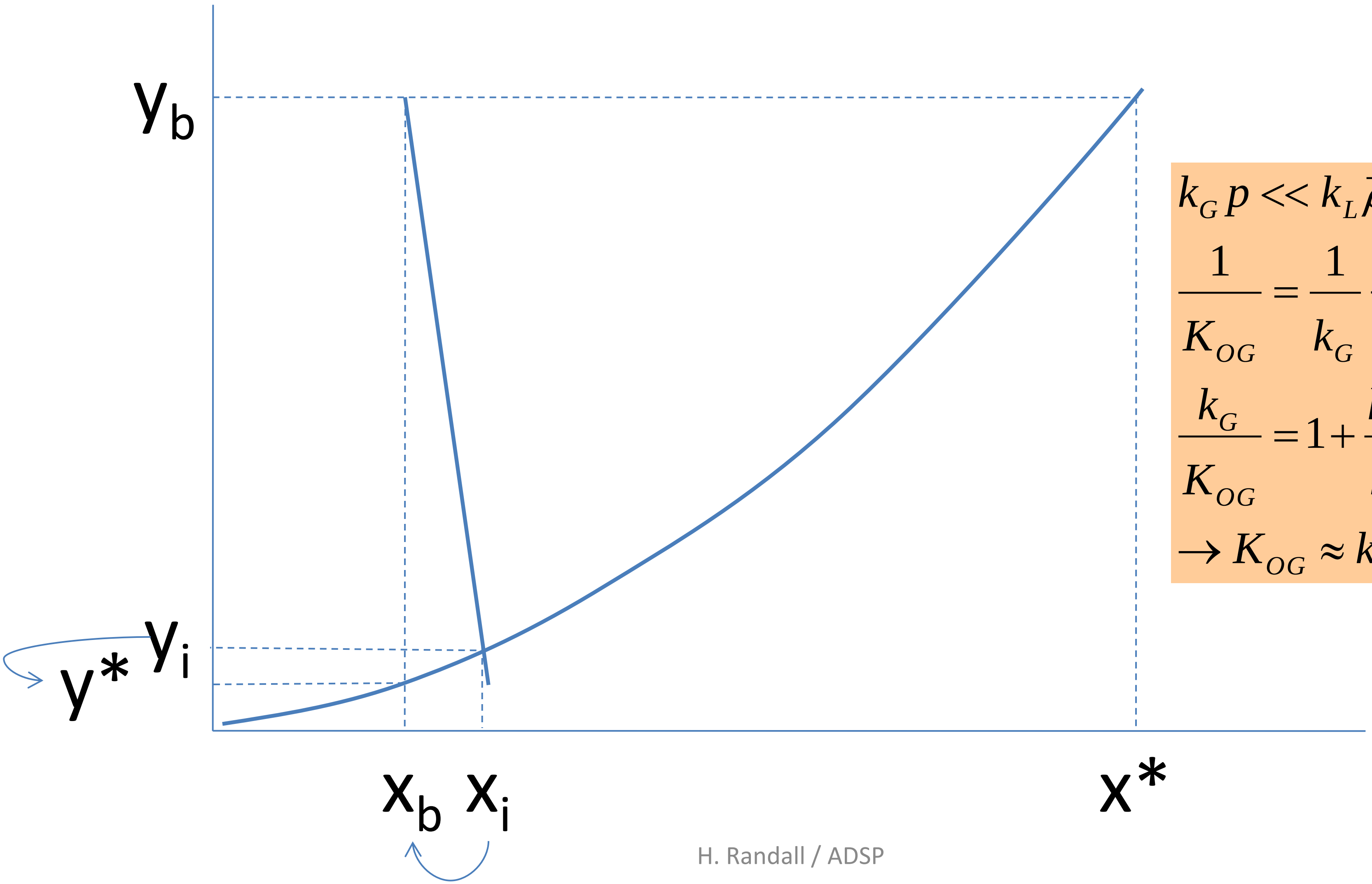
$$\left(Y_f\right)_A = \frac{\left(1 - t_A y_b\right) - \left(1 - t_A y_i\right)}{\ln\left(\dfrac{1 - t_A y_b}{1 - t_A y_i}\right)}$$

$$\left(X_f\right)_A = \frac{\left(1 - t_A x_b\right) - \left(1 - t_A x_i\right)}{\ln\left(\dfrac{1 - t_A x_b}{1 - t_A x_i}\right)}$$

Two-film theory



High $(k_L\,\rho)$ / $(k_G\,P)$ ➔ gas film controls



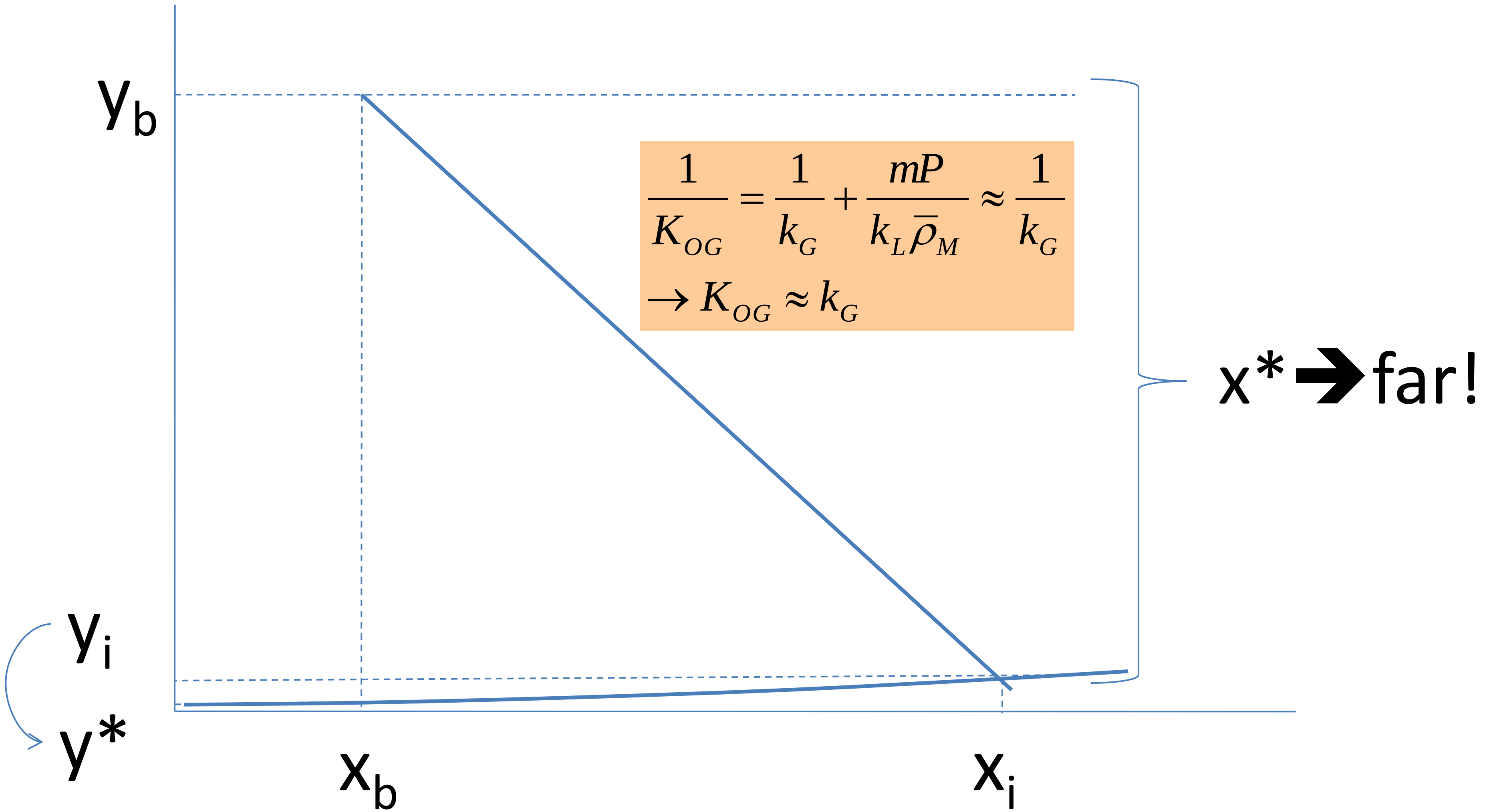
$$k_G\,p << k_L\,\bar{\rho}_M$$

$$\frac{1}{K_{OG}} = \frac{1}{k_G} + \frac{mP}{k_L\,\bar{\rho}_M}$$

$$\frac{k_G}{K_{OG}} = 1 + \frac{k_G\,mP}{k_L\,\bar{\rho}_M} \approx 1$$

$$\rightarrow K_{OG} \approx k_G$$

Low *m* (high solubility) ➔ gas film controls

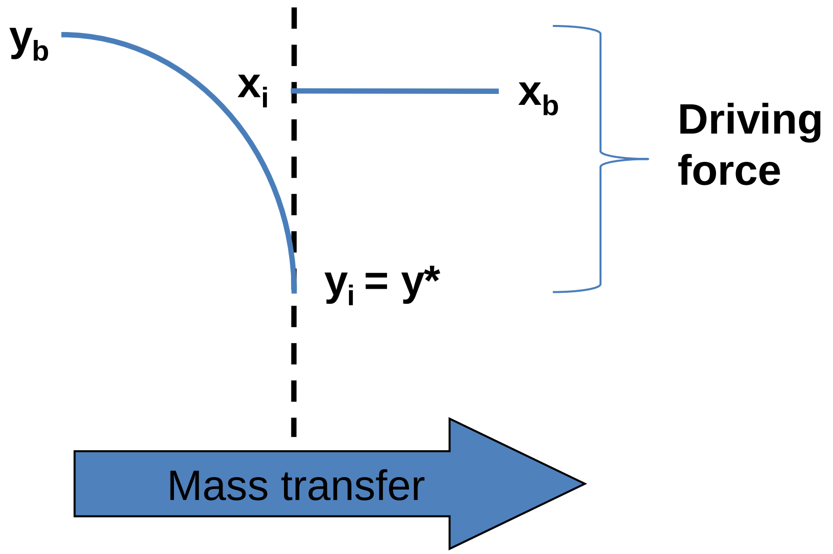


$$\frac{1}{K_{OG}} = \frac{1}{k_G} + \frac{mP}{k_L \bar{\rho}_M} \approx \frac{1}{k_G}$$

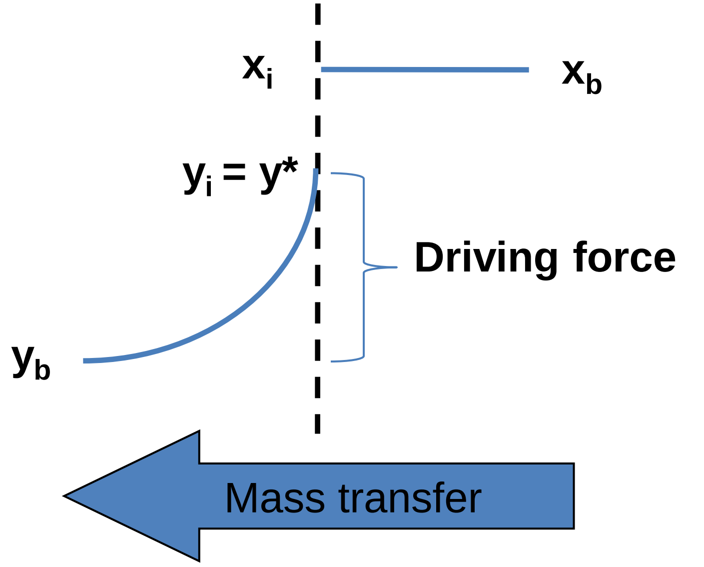
$$\rightarrow K_{OG} \approx k_G$$

Concentration profiles for gas film control

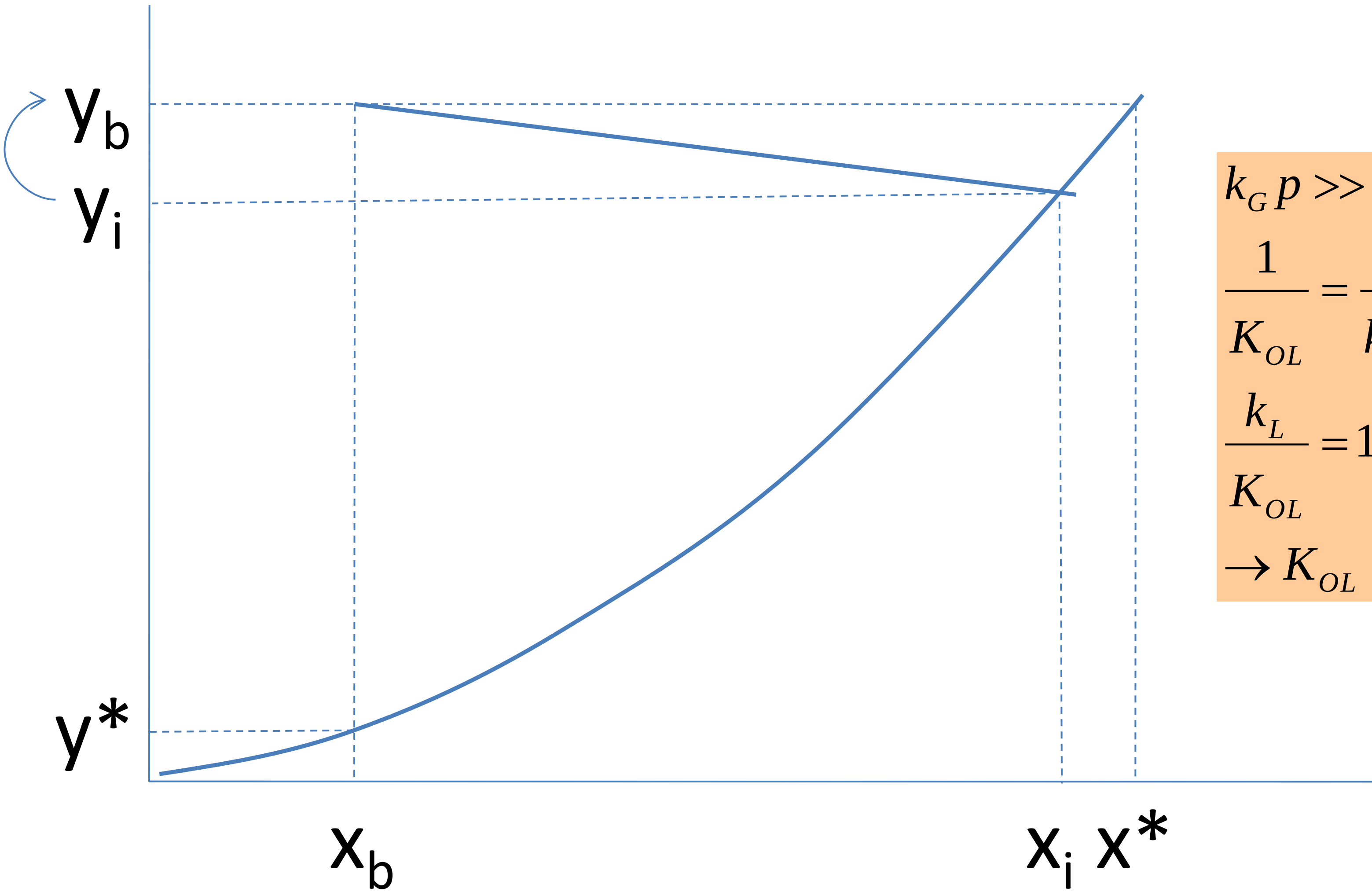
Absorption
-High $(k_L \rho_M) / (k_G P)$
-High solubility gas (low m)



Stripping or evaporation
-Stripping with high $(k_L \rho_M) / (k_G P)$
-Stripping of high solubility gas
-Evaporation of pure liquid



Low $(k_L \rho) / (k_G P)$ ➔ liq. film controls



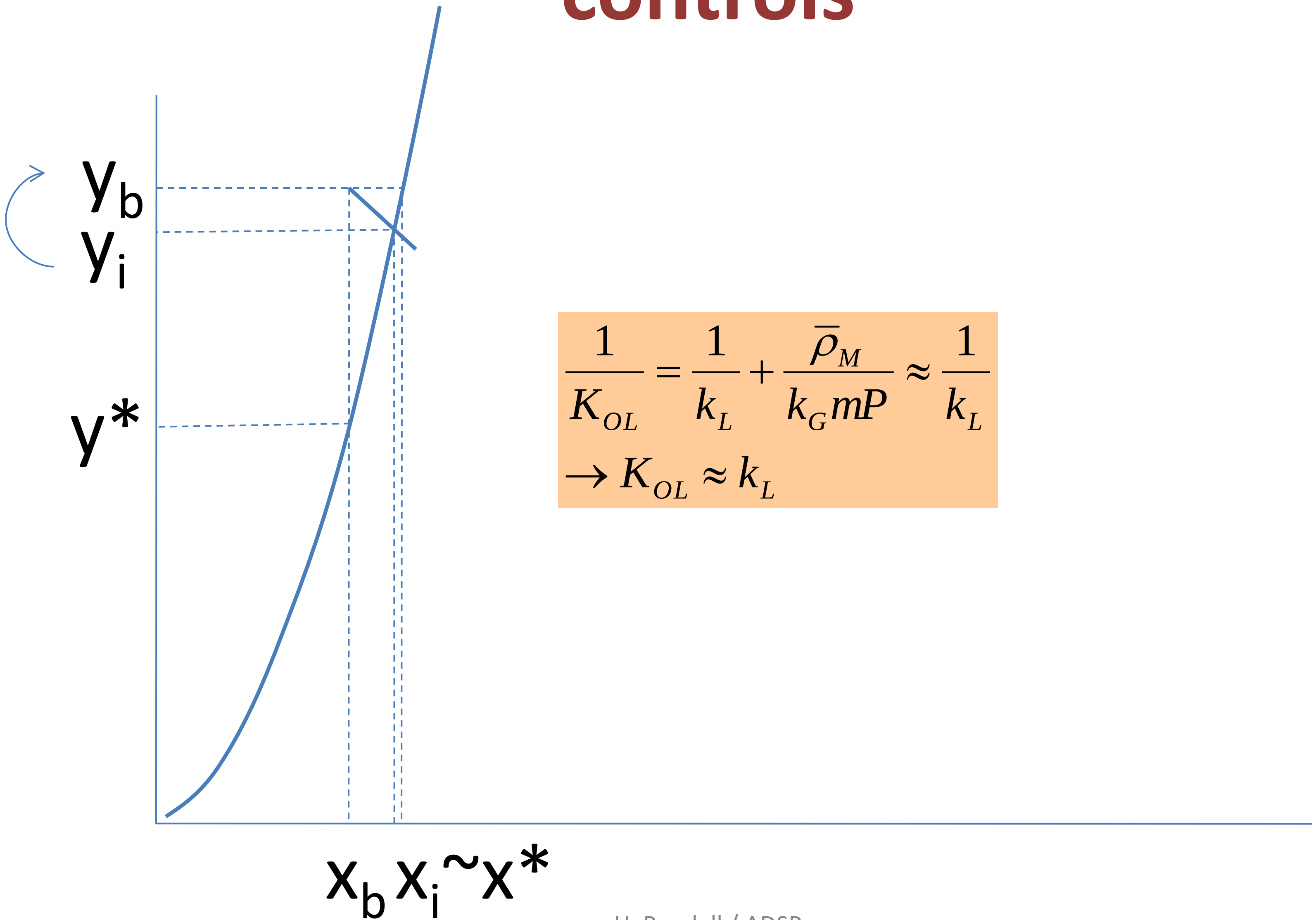
$$k_G p >> k_L \bar{\rho}_M$$

$$\frac{1}{K_{OL}} = \frac{1}{k_L} + \frac{\bar{\rho}_M}{k_G mP}$$

$$\frac{k_L}{K_{OL}} = 1 + \frac{k_L \bar{\rho}_M}{k_G mP} \approx 1$$

$$\rightarrow K_{OL} \approx k_L$$

High *m* (low solubility) ➔ liquid film controls

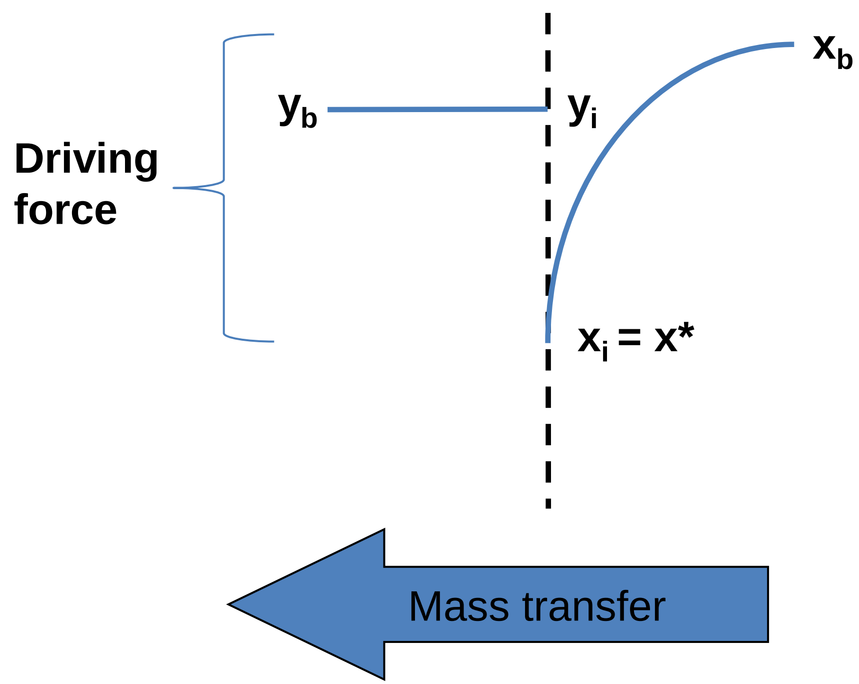


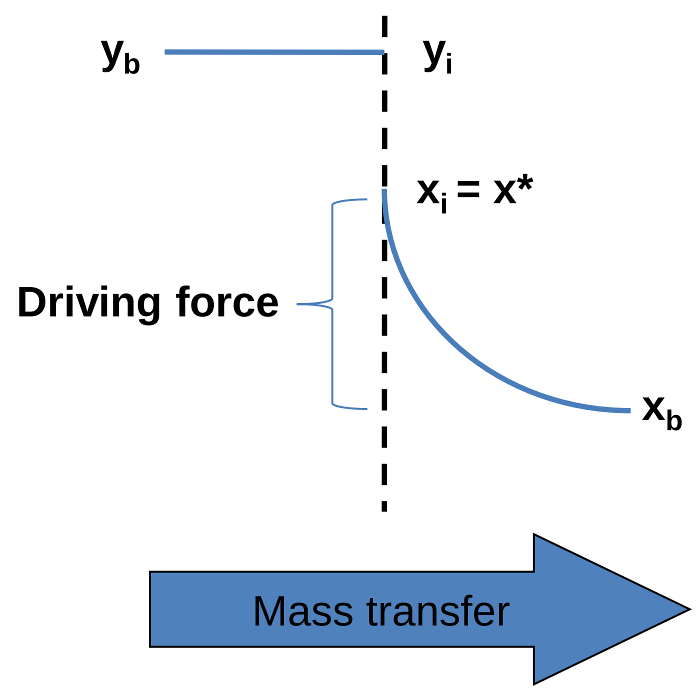
$$\frac{1}{K_{OL}} = \frac{1}{k_L} + \frac{\bar{\rho}_M}{k_G m P} \approx \frac{1}{k_L}$$
$$\rightarrow K_{OL} \approx k_L$$

Concentration profiles for liquid film control

Stripping
-Low $(k_L \rho_M) / (k_G P)$
-Low solubility gas

Absorption
-Low $(k_L \rho_M) / (k_G P)$
-Pure or low solubility gas





Measurement of k_L and k_G

- **To measure k_L**
  - Absorb or desorb (strip) gas with low solubility
  - Absorb pure gas
- **To measure k_G**
  - Absorb or desorb (strip) gas with high solubility
  - Evaporate pure solvent

Henry's law
(used to calculate interfacial concentrations)

Different possible forms of the equation

$$p_A = H_A x_A$$

$$p_A = \frac{c_A}{H_A}$$

$$y_A = H_A x_A$$