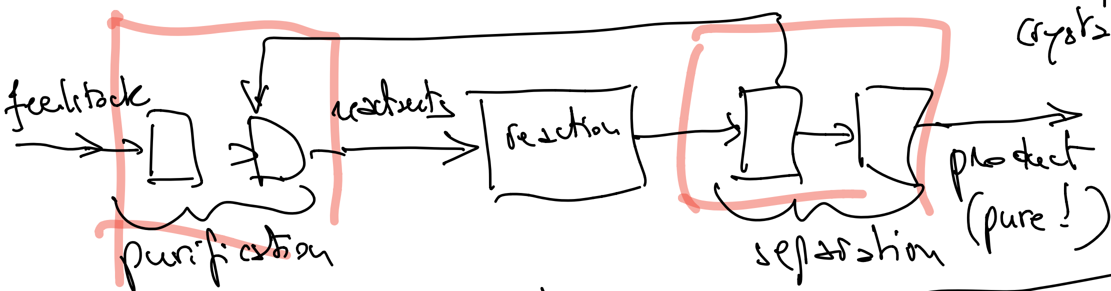
Rate Controlled Separations

Separation Process Technology
- gas - liquid sep.
- liquid - liquid sep.

Kinetics & equilibrium

membranes
adsorbents
crystalliz.




unit operation
- membranes
- distillation
- absorption

short-cut design methods

## ABSORPTION

- •) air containing VOCs, to be removed by an organic solvent
- •) flue gas, containing $CO_2$, to be captured using a solvent aqueous solution of amines, $NH_3$, hydroxide

$\Delta \mu_{pollutant} = 0$

$T_L = T_G \Leftrightarrow$ thermal eq.

$P_L = P_G \Leftrightarrow$ mechanical eq.

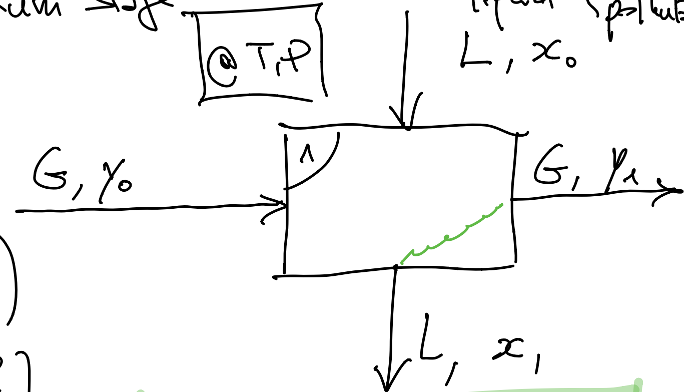
$\mu_i^L = \mu_i^G \Leftrightarrow$ eq. w.r.t. mass transfer

thermodynamic equilibrium
multi phase
multi component

stage / contact stage / contactor

equilibrium stage $\boxed{@\,T,P}$

liquid (solvent, pollutant) $L, x_0$ ~ thermodynamic equilibrium




gas (carrier gas, pollutant)

$G, L \left[\frac{mol}{s}\right]$

$x, y$ [-]

→ only the pollutant is transferred

→ $G, L$ are constant ~ diluted

→ steady state

- material balance
- thermodynamic eq.:

$$\mu_1^L = \mu_1^G$$

## single component ideal gas

$PV = nRT$ } ideal gas law | Eq. of state

$\boxed{Pv^* = RT}$

$$\left(\frac{\partial \mu^*}{\partial P}\right)_T = \left(\frac{\partial V}{\partial n}\right)_P = v^*$$

@ T $\quad d_T\mu^* = v^* dP = \frac{RT}{P} dP = \boxed{RT\, d_T \ln P = d_T\mu^*}$

## single component real gas

EOS $\quad \frac{Pv}{RT} = Z$ compressibility $\begin{cases} Z=1 & \text{ideal gas} \\ Z\neq 1 & \text{real gas}\end{cases}$

virial EOS $\quad \frac{Pv}{RT} = 1 + B(T)P = Z$

$$\left(\frac{\partial \mu}{\partial P}\right)_T = \left(\frac{\partial V}{\partial n}\right)_P = v \qquad d_T\mu = \boxed{v\, dP = \boxed{RT\, d_T \ln f} = d_T\mu}$$

$f$: fugacity $\qquad P \to 0 \quad f \sim P \qquad \lim_{P\to 0} \frac{f}{P} = 1$

$$\int_{f_2}^{f} \boxed{d_T \ln f = \int_{P_2}^{P} \frac{v}{RT} dP}$$

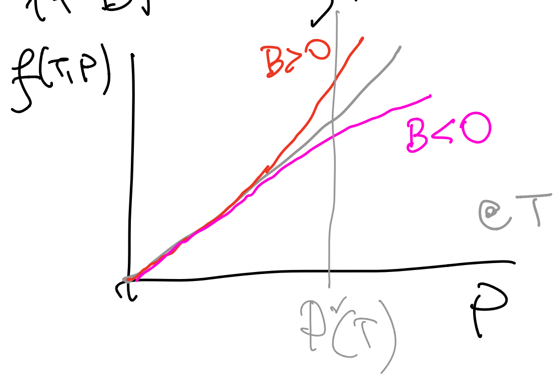
$$\boxed{\ln \frac{f(T,P)}{f(T,P_2)} = \int_{P_2}^{P} \frac{Z}{P} dP} \ominus \boxed{\ln \frac{P}{P_2} = \int_{P_2}^{P} \frac{dP}{P}}$$

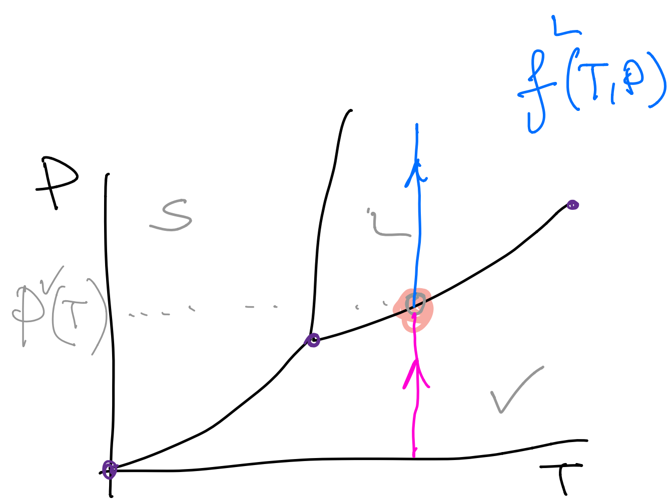
$$\boxed{\ln\left(\frac{f(T,P)}{f(T,P_2)}\frac{P_2}{P}\right) = \int_{P_2}^{P} \frac{Z-1}{P} dP} \longrightarrow P_2 \to 0$$

$$\ln \frac{f(T,P)}{P} = \int_0^P \frac{z-1}{P}\, dP$$

$$\boxed{f^V(T,P) = P \exp\left(\int_0^P \frac{z(T,P)-1}{P}\, dP\right)}$$

Ex. $\quad z = 1 + BP \qquad f^V(T,P) = P \exp(BP)$




$\boxed{\text{Single component liquid}}$

$$d_T \mu^L = \boxed{v^L dP = RT\, d_T \ln f^L}$$

$$\boxed{\int_{f_2^L}^{f^L} d_T \ln f^L = \int_{P_2}^{P} \frac{v^L}{RT}\, dP} = \boxed{\frac{v^L (P - P_2)}{RT} = \ln \frac{f^L(T,P)}{f^L(T,P_2)}}$$

$$f^L(T,P) = f^L(T,P_2) \exp\left(\frac{v^L (P - P_2)}{RT}\right) = \left\{ P_2 = P^V(T) \right\}$$

$$= \boxed{f^V(T, P^V(T))} \exp\left(\frac{v^L (P - P^V(T))}{RT}\right) =$$

$$\boxed{f^L(T,P) = \boxed{P^V(T) \exp\left(\int_0^{P^V(T)} \frac{z(P,T) - 1}{P}\, dP\right)} \exp\left(\frac{v^L (P - P^V(T))}{RT}\right)}$$

$v^L$ = small $\qquad f^L(T,P) = f^L(T, P^V(T)) = \boxed{f^V(T, P^V(T))}$

gas ≃ ideal $\qquad \boxed{f^L(T,P) = P^V(T)}$