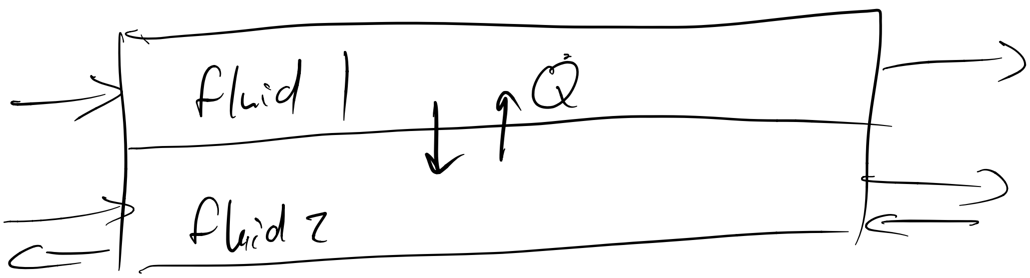
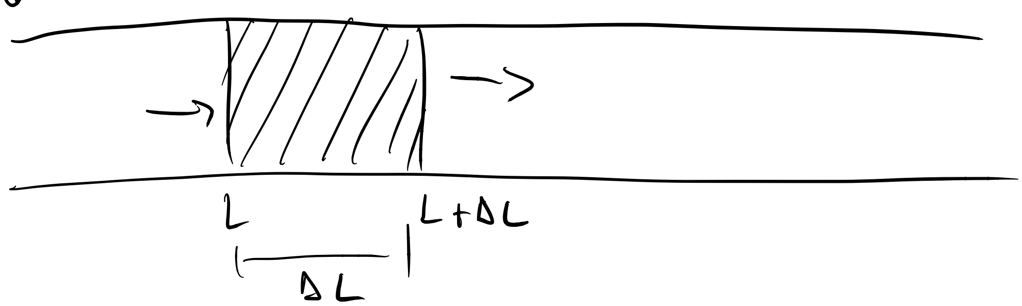
let's start



zoom in of stream 1



$$\text{mass @ } t+\Delta t \;-\; \text{mass @ } t \;=\; \left(\dot{m}_{in}\Big|_{L} \text{ in } \Delta t \;-\; \dot{m}_{out}\Big|_{L+\Delta L} \text{ in } \Delta t \right) \Delta t$$

steady-state operation $\rightarrow$ $0 = \left(\dot{m}_{L} - \dot{m}_{L+\Delta L} \right) \Delta t$

Energy Balance

$$\underset{@\ t+\Delta t}{\text{energy}} - \underset{@\ t}{\text{energy}} = E_{in}\Big|_L - E_{out}\Big|_{L+\Delta L} + \text{energy flow due to heat transfer.}$$

Steady - state

$$0 = \dot{m}_L \hat{H}_L \Delta t - \dot{m}_{L+\Delta L} \hat{H}_{L+\Delta L} \Delta t + \dot{Q} \Delta L \Delta t$$

stream 1

$$\dot{M}\left(\hat{H}_{L+\Delta L} - \hat{H}_L\right) = \dot{M} C_p \left(T_{L+\Delta L} - T_L\right) = \dot{Q} \Delta L$$

$$\Delta L \to 0$$

Stream 1: $$\dot{M} C_{p_1} \frac{dT_1}{dL} = \dot{Q}$$

$$\dot{Q} \underset{\substack{\uparrow \\ \text{by problem statement}}}{\equiv} k\left(T_2 - T_1\right)$$

stream 2

$$\dot{M}_2 C_{p_2} \frac{dT_2}{dL} = -Q = -k\left(T_2 - T_1\right)$$

$\dot{M}_1$, $\dot{M}_2$ for co-current flow → same direction are both positive.

$\dot{M}_1 = \dot{M}_2$ and $C_{p_1} = C_{p_2}$

1) $\dot{M}_1 C_{p_1} \dfrac{dT_1}{dL} = K (T_2 - T_1)$

2) $\dot{M}_2 C_{p_2} \dfrac{dT_2}{dL} = -K (T_2 - T_1)$

in general → solve the linear algebra problem, or use a computer.

but here, if $\dot{M}_1 C_{p_1} = \dot{M}_2 C_{p_2}$

add 1 + 2 →

$$\underbrace{\frac{dT_1}{dL} + \frac{dT_2}{dL}} = 0$$

$$\frac{d(T_1 + T_2)}{dL} = 0$$

$$T_1 + T_2 = C$$

a constant

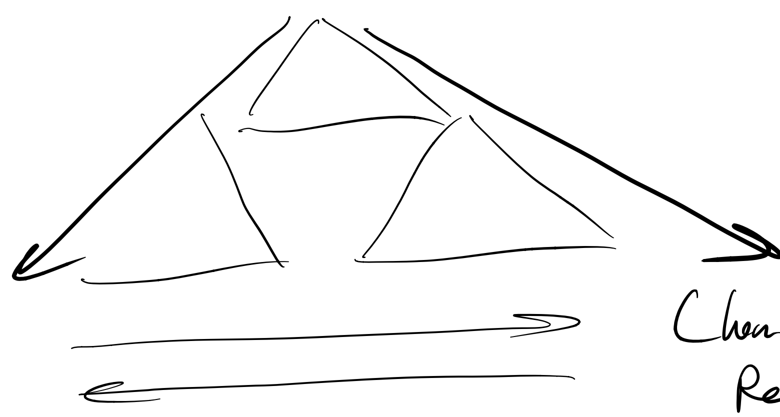
$$T_2 = C - T_1$$

go back to 1)

$$\longrightarrow \quad \frac{dT_1}{dL} = \frac{K}{\dot{M} C_p}\left(C - 2T_1\right)$$

Gibb's Free Energy

Useful Energy that is accessible to do stuff with @ constant T, P



VLE
Vapor Liquid Equilibrium

Chemical Reactions

Phases

We have our tools + I.G. for our primary Equation of state for a Real substance EOS

We need a bit more realistic EOS

In each of our state functions,

$$d\underline{S} \to T, V, P$$
$$d\underline{E} \to T, V, P$$
$$d\underline{H} \to T, V, P$$
$$d\underline{G} \to T, V, P$$

We have IG

$$P\underline{V} = RT$$

but only for ideal cases.

How to handle non-ideal?

- Have tabulated data in a table
- graphical data
  - ↳ fit by some "function"

We focus here on these curves

Simplest + historically important

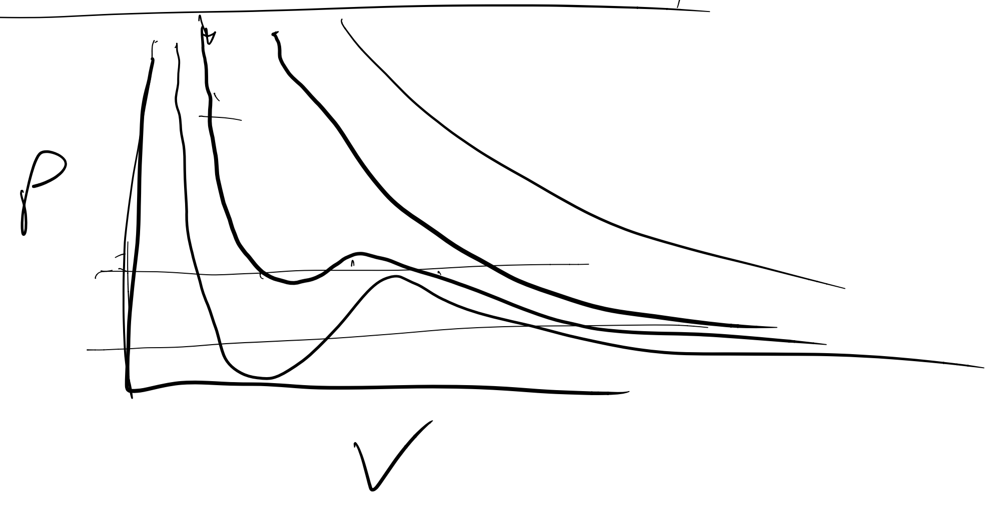
Vander Waal's EOS

↳ developed in 1873 →

13 years before PBR got the blue Ribbon

Nobel Prize in 1910

$$\boxed{P = \frac{RT}{\underline{V} - b} - \frac{a}{\underline{V}^2}}$$



Derived by measurement of non-ideal behavior

Better than IG, but still not very good for most real substances

Evolution of these equations
→ they are a little better.

1873 → 1970's ~ 100 years

"Peng - Robinson" EOS

$$\boxed{P = \frac{RT}{\underline{V} - b} - \frac{a(T)}{\underline{V}(\underline{V}+b) + b(\underline{V}-b)}}$$

$$a(T) = 0.45724 \frac{R^2 T_c^2}{P_c} \alpha(T)$$

$$b = 0.07780 \frac{R T_c}{P_c}$$

$$\sqrt{\alpha(T)} = 1 + K\left(1 - \sqrt{T/T_c}\right)$$

$$K = 0.37464 + 1.54226 w - 0.26992 w^2$$

$$w = -1.0 - \log_{10}\left(\frac{P_{vap_{T_r = 0.7}}}{P_c}\right)$$

$T_r = T/T_c$ $\quad$ P_c = Critical Pressure

T_c = Critical Temp $\quad$ P_{vap} = vapor pressure

These equations, PR, VW are special cases of

$$P = \frac{RT}{\underline{V}-b} - \frac{(\underline{V}-\eta)\,\theta}{(\underline{V}-b)(\underline{V}^2+\delta\underline{V}+\varepsilon)}$$

$b, \theta, \delta, \eta, \varepsilon$ can all depend on T

η

all determined by experiment

All of these equations can be re-written as:

$$\boxed{Z^3 + \alpha Z^2 + \beta Z + \gamma = 0}$$

That's why these are all called cubic equations of state $Z = \frac{P\underline{V}}{RT}$ "compressibility factor" solve:

$$az^2 + bz + c = 0$$

$$\boxed{z = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}}$$

so solve the other one.

GOOD LUCK!