Equipment Sizing Based on Heuristics

Equipment Sizing

- An order-of-magnitude estimate is usually sufficient for preliminary design calculations.
- This estimate has an error of 25-40%
- We will consider equipment sizing heuristics for the following:
  - Vessels
  - Heat Transfer Equipment
  - Distillation Columns
- All these calculations require flow rate, temperatures, pressures and heat duties from the flowsheet and energy balance.

Vessel Sizing

Vessels include flash drums, storage tanks, decanters and some reactors. Unless specified otherwise by particular unit requirements, these will be sized by the following criteria:

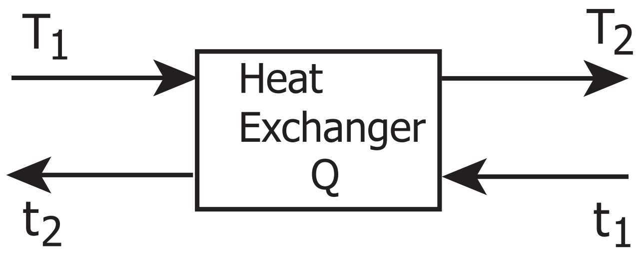
- Select vessel volume V based on a five-minute liquid holdup time with an equal volume added for vapor flow:

$$V = 2\left[\frac{F_L \tau}{\rho_L}\right]$$

F_L	liquid flow rate leaving the vessel
ρ_L	density of liquid
τ	residence time (5 minutes)

- Specification of the residence time is dictated by maintaining a liquid buffer for on/off switching times for pumps.
- The aspect ratio $\frac{L}{D} = 4$.
  This ratio is optimal if bottom and top heads are 4 times as expensive as sides.
- If $D > 4\ ft$ size the unit as a horizontal vessel.
  This requires more space but costs less for structural support.
- As a safety factor, choose the vessel (gauge) pressure to be 50% higher than the actual pressure from the material and energy balance.
- For desired temperature range, consider the required material of construction.

Heat Transfer Equipment



Consider a counter-current shell-and-tube heat exchanger.

- Heat transfer area can be found from:

$$Q = UA\Delta T_{lm}$$

  where

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{ln\left[\frac{T_1 - t_2}{T_2 - t_1}\right]}$$

- The overall heat transfer coefficient, U, can be estimated from heuristics or from standard references (e.g. Perry's Handbook)

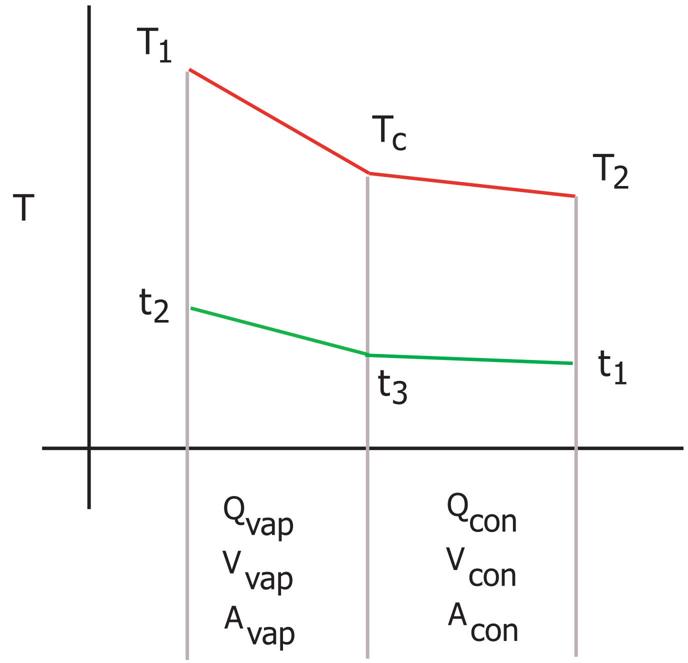
- If there is a phase change, the overall heat transfer coefficient, U, changes.
- This case is modeled as two heat exchangers in series, each with a different U and A.

$$A_{vap} = \frac{Q_{vap}}{U_{vap}\Delta T^a_{lm}}$$

where $\Delta T^a_{lm} = \dfrac{(T_1 - t_2) - (T_c - t_3)}{ln\left[\dfrac{T_1 - t_2}{T_c - t_3}\right]}$

$$A_{con} = \frac{Q_{con}}{U_{con}\Delta T^b_{lm}}$$

where $\Delta T^b_{lm} = \dfrac{(T_c - t_3) - (T_2 - t_1)}{ln\left[\dfrac{T_c - t_3}{T_2 - t_1}\right]}$



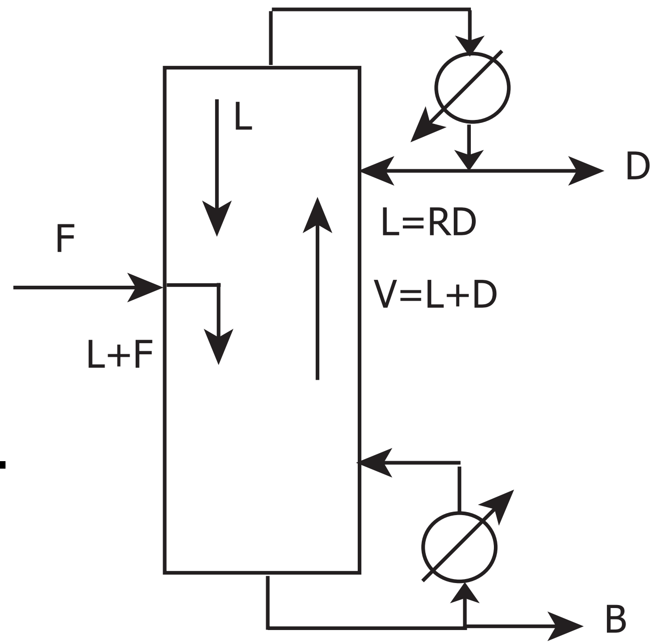
T versus Heat Exchanged

- We choose $10,000\ sq.\ ft.$ as the maximum exchanger area. If more area is required, multiple heat exchangers in parallel are used.

Distillation Column

1. Determine actual number of trays and reflux ratio.
2. Calculate column diameter and height as follows:

   To determine the diameter, design the column to run at 80% of the flooding velocity.
   At the flooding velocity, the vapor flow rate is so high that no net liquid flow occurs and entrainment begins.

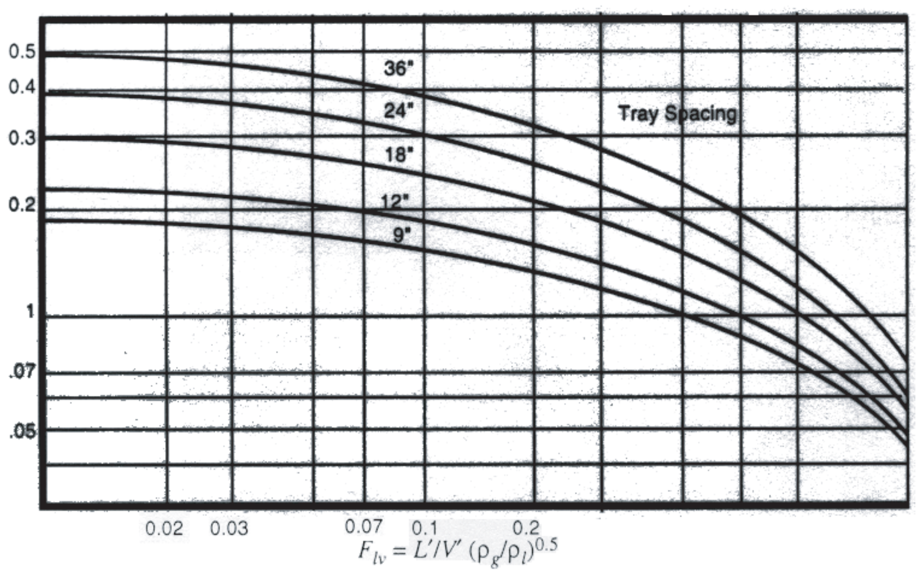


- Calculate dimensionless flow parameter F_{lv}

$$F_{lv} = \frac{L^{'}}{V^{'}} \left(\frac{\rho_g}{\rho_l} \right)^{0.5}$$

where $\frac{L^{'}}{V^{'}}$ is the liquid/gas mass ratio at the point of consideration and $\frac{\rho_g}{\rho_l}$ is the gas/liquid density ratio.

- Calculate capacity parameter $C_{sb,f}$ from the chart below for a given tray spacing:



- Calculate linear flooding velocity (ft/s) from

$$U_{nf} = C_{sb,f} \left(\frac{\rho_l - \rho_g}{\rho_g} \right)^{0.5} \left(\frac{\sigma}{20} \right)^{0.2}$$

where ρ_g and ρ_l are the gas and liquid mass densities and σ is the liquid surface tension in $dynes/cm$.

- Calculate area of cross-section from $A = \dfrac{V^{'}}{0.8 U_{nf} \epsilon \rho_g}$

where ϵ is the fraction of area available for vapor flow (0.6 for bubble cap trays and 0.75 for sieve trays).

- Calculate column diameter from

$$D = \sqrt{\frac{4A}{\pi}}$$

If $D > 20\ ft$, then split the column into two columns running in parallel.

- The number of actual trays is given by $\frac{N_T}{\eta}$ where the efficiency is assumed to be 80%. Assume a tray spacing of $24^{''}$ to calculate column height.
- Calculate heat duties for condenser and reboiler from energy balance.