Understanding and Specifying Process Conditions

Good judgement comes from experience, and experience comes from bad judgement

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Process Conditions

- A degree-of-freedom analysis of any unit operation suggests that there is flexibility in choosing *some* operating variables (temperature, pressure, stream composition etc.)
- Stream specifications and process conditions are influenced by physical processes as well as ecomomic considerations and are *not chosen arbitrarily*.
- The conditions used in a process most often represent an economic compromise between process performance and the capital and operating costs of the process equipment.

Separator and Reactor Operation

- Process streams are rarely available at conditions most suitable for reactor and separator units.
- Temperature, pressure and/or stream composition must be adjusted for effective process performance.
- It is easier to adjust temperature and pressure of a process stream than it is to change its composition.
- A decision to operate outside the pressure range of 1 to 10 bar must be justified.
- A decision to operate above 400 ^{o}C must be justified.
- A decision to operate outside the temperature range 40 ^{o}C to 260 ^{o}C requires special heating/cooling media, and thus must be justified.

Reactor Operation at High Temperature

- Favorable equilibrium conversion
  - If the reaction is endothermic and approaches equilibrium, it benefits from high temperature.
  - If the reaction is exothermic and approaches equilibrium, it benefits from low temperature.
- Increase reaction rate
  - $k = k_0 exp\left(-\frac{E}{RT}\right)$
  - As temperature increases, specific reaction rate k increases.

- Maintain a gas phase
  - Many catalytic reactions require gas phase for reactants and products.
  - If boiling points are high or pressure is high, a high temperature may be required.
- Improve selectivity
  - If competing reactions occur and different reactions have different activation energies, an appropriate temperature is needed to favor the desired reaction.

Separator Operation at Low Pressure

- Obtain gas phase for vapor-liquid equilibrium
  - This situation arises quite frequently when high boiling point materials are needed to be distilled.
  - An example is the distillation of crude oil in which the bottom of the atmospheric column is typically operated in the region of $310\ ^oC$ to $340\ ^oC$.
- Temperature sensitive material
  - This situation arises frequently in the manufacture of specialty chemicals.
  - Examples of material that are temperature sensitive are fragrance chemicals, flavor chemicals, pharmaceuticals.

Product Present in Reactor Feed

Having products in the feed to the reactor usually imply a potential loss of profit. However, products may be present in the feed under the following conditions:

- Product cannot be easily separated from recycled feed material.
- Recycled product retards the formation of unwanted by-products formed from side reactions.
- Product acts as a diluent to control the rate of reaction.

Reading Assignment

Read Chapter 4 from TBWS.
In particular, please study the following tables in detail.

- Table 4.1: Possible reasons for operating reactors and separators outside the temperature range of special concern (page 120)
- Table 4.2: Possible reasons for operating reactors and separators outside the pressure range of special concern (page 121)
- Table 4.3: Possible reasons for nonstoichiometric reactor feed compositions of special concern (page 122)
- Table 4.4: Changes in process conditions that are of special concern for a stream passing through a single piece of equipment (page 124)

Heuristics in Design

It is important to be able to apply knowledge gained through experience to future problems.

- Heuristics are useful in rapidly determining feasibility of a process design.
- A heuristic does not guarantee a solution.
- It may contradict other heuristics.
- It can reduce the time to solve a problem.
- It's acceptance depends on the immediate context instead of on an absolute standard.

Physical Property Heuristics

	Units	Organic Liq.	Organic Vap.
Heat Capacity	kJ/kg^oC	$1.0 - 2.5$	$2.0 - 4.0$
Thermal Cond.	W/m^oC	$0.10 - 0.20$	$0.02 - 0.06$
Viscosity	kg/ms	wide range	$10 - 30 \times 10^{-6}$
Prandtl No.		$10 - 1000$	$0.7 - 0.8$

Heuristics for Distillation Towers

- Distillation is usually the most economical method for separating liquids.
- For multicomponent mixtures:
  - Perform the easiest separation first.
  - When neither relative volatility nor feed composition vary widely, remove components one by one as overhead products.
  - When the adjacent ordered components in the feed vary widely in relative volatility, sequence the splits in order of decreasing volatility.
  - When the concentrations in the feed vary widely but the relative volatilities do not, remove the components in order of decreasing concentration.

- Tower operating pressure is usually determined by temperature of the condensing media or by the maximum allowable reboiler temperature.
- Economical optimum reflux ratio is in the range of 1.2-1.5 times the minimum reflux ratio.
- The economically optimum number of theoretical stages is near twice the minimum value.
- Reflux drums are usually horizontal, with a liquid holdup of 5 minutes half full.
- Tower height is limited to about 53 m.

Heuristics for Heat Exchangers

- In a shell and tube heat exchanger, the tube side is for corrosive, fouling, scaling and high pressure fluids.
- In a shell and tube heat exchanger, the shell side is for viscous and condensing fluids.
- Pressure drops are 0.1 bar for boiling, and 0.20-0.62 bar for other services.
- Minimum temperature approach is 10^oC for fluids and 5^oC for refrigerants.
- Cooling water inlet is 30^oC and maximum outlet is 45^oC.
- Double-pipe heat-exchanger is competitive at duties requiring 9.3-18.6 m^2.
- Heat transfer coefficients (in W/m^2K) for estimating purposes:

Reading Assignment

Read Chapter 9 from TBWS.
In particular, please study the tables 9.2-9.18 (pages 337-352) in detail.