Chemical Engineering - Separations 5

Lecture 3 – heat integration

John Christy

Aims

- Use process duties instead of utilities, i.e. heat integration. (hot utility: steam, cold utility: cooling water or refrigeration.)

Strategies

- avoid large ΔT across heat exchangers, eg use steam at lowest convenient temp in reboilers
  - don't use cooling water to condense hot distillate (eg well over 100°C)
    - loss of "available energy" or "exergy" $B = H - T_0 S$
  - strategies include
    - 2-stage condensation
    - use of pumparounds/ intermediate reboiler & condenser
    - use of heat pumps

Strategies

- Insulate (?): may eliminate dynamic excursions due eg to rainstorms
- pre-heat feed with hot products
- integrate condenser/reboiler of adjacent columns
- avoid over-separation: both in design and operation

Strategies

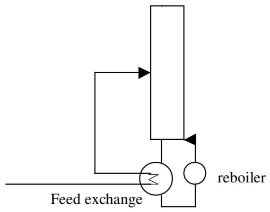
- minimise reflux in design of sequence (hence Q_R and Q_C) cf ΔV method
- minimise MSA circulation rates: seek solvents with large selectivity for component to be extracted
- Don't mix streams of widely different composition or temperature
- minimise ΔP in column if pressure related costs are important

Process stream exchangers

- Traditionally hot bottoms products used to preheat feed
- Nowadays heat exchanger network synthesis methodologies identify best use of all hot and cold process streams
  - Pinch technology (Linnhoff): heuristics, but valuable insight using concept of process pinch
  - MINLP (eg Westerberg): set up stream matching as a large optimisation problem. Problems of obtaining solution and of finding global optimum

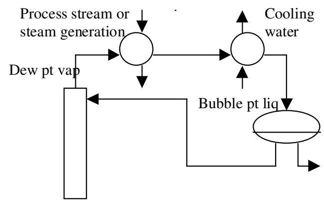
‘Hot’ Feeds

- If feed has excess heat (eg hot vapour from reactor, air feed in cryogenic distillation), it can be used to provide reboil



Two-stage condensation

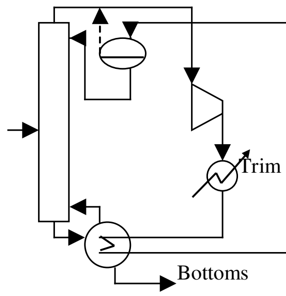
- Proposed for wide-boiling column overhead (large ΔT between top tray and bubble point)



Vapour recompression

- Compress overhead vapour to a pressure such that its temperature exceeds that required in the reboiler
- condense overheads to provide partial vaporisation of bottoms stream
- throttle/flash liquid back to column pressure
- possibly recycle vapour
- need trim cooling for control

Vapour recompression



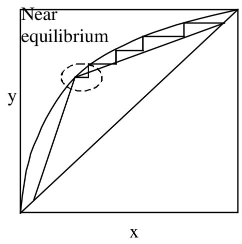
Vapour recompression

- This makes a heat pump
- works well if $T_R - T_C$ small: get high coefficient of performance
- But
  - heat pump involves mechanical inefficiency of compressor (cf direct heating of steam)
  - extra equipment cost (compressor). Note we compress all the vapour flow
  - often not really worthwhile, except if we would otherwise have to chill the condenser

Intermediate reboiler/condenser

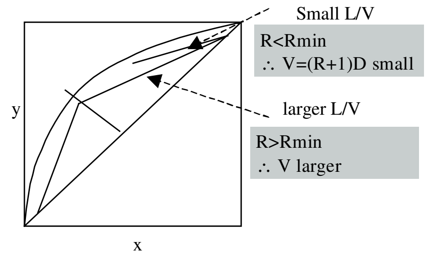
- Composition and temperature of streams L_{n+1} & V_{n-1} entering a stage differ $T_{n+1} \neq T_{n-1}$ and $K_{n+1}x_{n+1} \neq y_{n-1}$ therefore entropy is produced by mixing
- To make column as reversible as possible, require entering streams close to equilibrium with each other
- This happens at a feed pinch

Intermediate reboiler/condenser



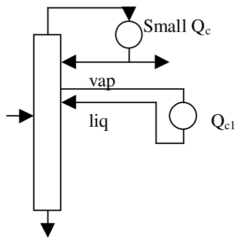
- But column sections away from feed are still irreversible

Intermediate reboiler/condenser



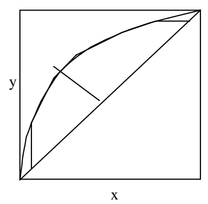
- Use intermediate condenser to get closer to reversibility

Intermediate reboiler/condenser



- Use cooling medium at close to local tray temp to minimise irreversibility

Intermediate reboiler/condenser



Would need many trays, many condensers

Extreme case clearly uneconomic

- In limit, do a little cooling on each tray above feed & heating on each tray below feed
- Sometimes worthwhile to put in one intercooler and one interheater

Intermediate reboiler/condenser

- NB intercooling or interheating does not change the total amount of heat removed or supplied
- It improves the thermodynamic efficiency of the separation process at a cost in
  - number of stages
  - extra kit, to perform the heating/cooling (pipework, exchangers, valves, pumps, etc)

Two-column integration

- Use heat of condensation from column 1 (typically high pressure) to provide reboil heat for column 2 (typically low pressure)
  - eg 1: split feed into two. Run two columns at different pressures. Provide parallel product streams
  - eg 2: Partially fractionate in C1, pass products into C2 as feeds (at appropriate stages). Complete the separation in C2.
    C1 products are relatively impure ∴ low ΔT across C1

Two-column integration

- Further possibility: tops vapour from first column enters appropriate stage in second column: liquid from that stage is returned to the first column as reflux. Similar arrangement applies for bottoms liquid.
- Similar to intercooling/interheating
- prefractionator does some of separation using heat/cooling supplied by sidestreams from main column. (Petlyule Towers)
- Can obtain relatively pure sidestream from main column (3 products, 2 columns, but only 1 reboiler and 1 condenser)