Process Design

references: Peters & Timmerhaus
Douglass
Perry's
Kirk-Othmer Encyclopedia

Best way to study for this part of the exam is to get a job in industry for about 10 yrs. Barring that, memorize how to make several compounds. And, always keep in mind Heuristics & common sense.

Therefore, a lot of what is in these notes is just common sense - We don't mean to offend your intelligence.

Pumps and Compressors

Factors for pump selection
- amount of fluid — Q
- properties ; ρ, μ — ρ, μ
- head — ΔP

Reciprocating pump
- pumps in pulses
- good for high pressure
- good for pumping suspended solids.

Rotary positive displacement pumps
- for highly viscous fluids
- no solids ~~[illegible]~~ allowed

Centrifugal pumps
- Cheap
- good with solids
- no big heads
- no viscous fluids

Compressors

Fans - for $\Delta P \leq .5$ psi
Fans are for moving gasses — not compressing them

Blowers - $\Delta P \leq 50$ psig — $P_2 = 4P_1$ MAX

Compressors - ~~some~~ can deliver pressures as high as 4000 atm.
But a compressor usually has a compression ratio of 4:1 Therefore, to raise

$1 \to 4 \quad 4 \to 16 \quad 16 \to 64 \quad 64 \to 256$

a streams pressure from 1 atm to 200 atm.
4 compressors would be needed

- energy for isentropic compression > Energy for isothermal compression

i.g. isothermal comp.

$$\text{Power} = P_1 V_1 \ln \frac{P_2}{P_1}$$

- Be careful with corrosive materials
- pumping & compressing usually involves ΔT
- friction losses as well as head must be considered for ΔP

Packed towers

Gas Absorption

Liquid-Liquid Extraction

Know: rate & concentration of one stream

Do mass balance to determine outlet concentrations.
Use equilibrium data & correlations to determine number of transfer units, ht. of transfer unit, other stream flow rate.
Use correlations to determine tower diameter such that neither flooding nor holdup occur.

It is helpful to make your column bigger than needed (as long as you don't fall into one of the uncool regimes above) to allow for future increases in production. Adding 2 ft to the diameter & 5 ft to the ht. (for instance on a 15ft x 5ft column) adds very little in cost. & Packing is cheap (~\$10-\$100/ft³)

Other considerations:

Heat of absorption

Pressure drop through bed.

Heat exchangers - random thoughts -

put dirty material flow through tube side of Shell & tube exchanger. This is easier to clean.

baffles - raise pressure drop in shell side. Increase turbulence in skell side giving better heat transfer
types o' baffles : orifice, disk & dougnut

corrosive stream goes through tube side so only 1 material has to be made corrosive resistant, or replaced often.

high pressure stream - tube side ⇒ only tubes have to be made of expesive high-P material.

fluid vebcities affect film coefficient. large velocity gives large coeff. (this is good!) & large pressure drop (bad!)
viscous fluids must be pushed through quickly to get a decent film coeff., which raises pressuredrop.
Pressure drops, in general, are lower on Shell side, so put viscous fluids on shell side & use baffles.

Noncondensable gases (i.e. CO_2 in steam) should be vented to prevent buildup in exchr. Otherwise this buildup will form a film & mess up heat trans.

dissolved O_2 in water at high T is very corrosive to steel exchrs.

$Q = UA\Delta T_{ln}$ & $Q = \dot{m}C_pT$ do it all!

Cost ~ Transfer Area

Humidity & cooling towers

all defs. at P=1 atm

A = H_2O, B = Air, $\bar{P}$ = partial pressure H_2O, P^s = vapor pressure

Humidity, $\mathcal{H} = \frac{\text{mass vapor}}{\text{mass dry air}} = \frac{MW_A \bar{P}}{MW_B (1-\bar{P})}$

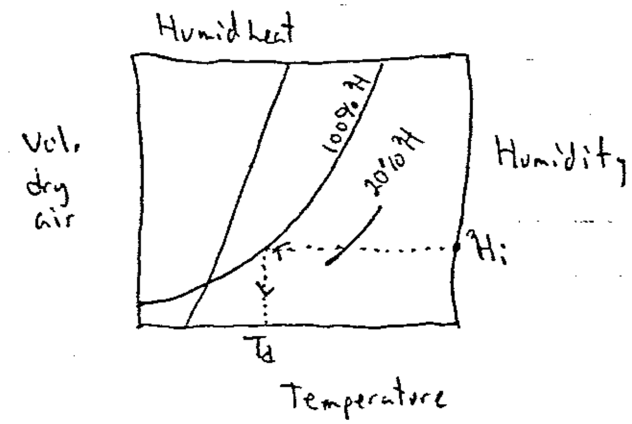
Saturated gas humidity (Vapor, Liq. Equil), $\mathcal{H}_S = \frac{MW_A P^s}{MW_B (1-P^s)}$

Relative humidity, $\mathcal{H}_R = 100 \frac{\bar{P}}{P^s}$

Air enthalpy, $H = C_{P,B}(T-T_{ref}) + \mathcal{H}\left[\Delta H^{vap} + C_{P,A}(T-T_{ref})\right]$

humidity Chart

dew pt., T_d = temperature at which condensation will occur (given $\mathcal{H}_i$)



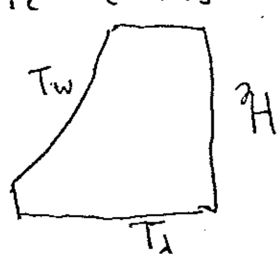
wet bulb temp., T_w is when rate of heat transfer to a water surface = rate of mass transfer away

$$K_g \Delta h^{vap} (P^s - \bar{P}) = h_c (T - T_w)$$

K_g = mass transfer coeff.
h_c = heat " "

dry bulb, T = air (humid) temp.

Psychrometric charts



Cooling towers are based on the principle that the water in the tower will try & reach equilibrium with the water in the air & will therefore evaporate. This evaporation takes the latent heat from the liquid H_2O, cooling it.

Usually designed as wet wall column with fans blowing air through center

Often cooling ~~box~~ ponds are used – these usually have a pump to spray a fountain of water & facilitate evaporation (The old increasing surface area to increase mass transfer trick)

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Question: My University is on the shore of Lake Michigan All the cooling water you could ever want. But our physical plant had a cooling pond anyway. Name 2 reasons.

1) There are heat pollution laws. You cannot release hot water directly into streams, ponds, etc.

2) Cooling water is usually treated. Softeners are added to reduce scaling on heat exchangers. So, why buy new softener when you can reuse old H_2O

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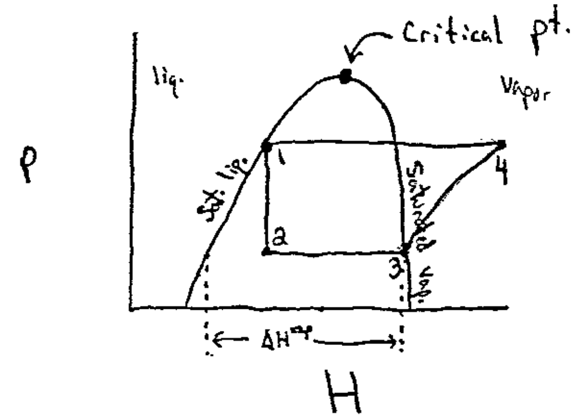
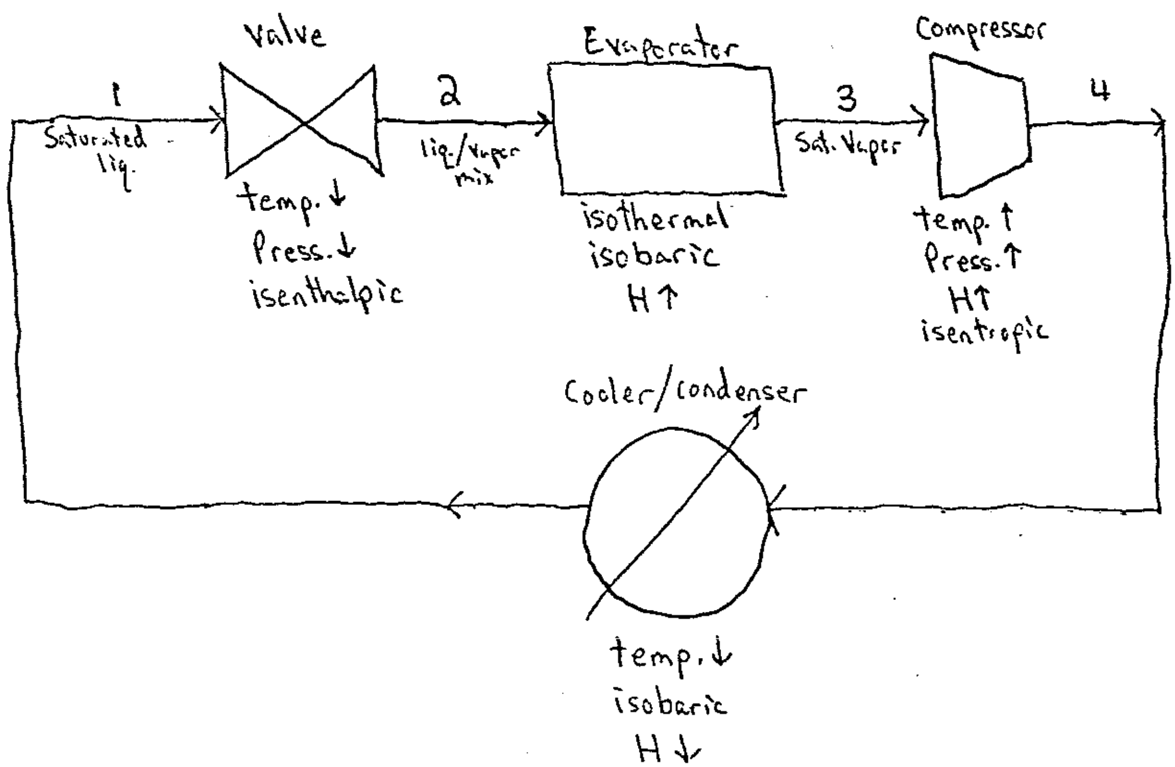
Remember you must add makeup H_2O to account for evaporation

Process H_2O obtained from a cooling tower is usually 80 – 90°F (not all that cold)

Refrigeration





Stream to be refrigerated is passed through evaporator

13 Feasibility Survey

The purpose of this survey is to preliminarily indicate the probable success of a project and to show what additional information is necessary to make a complete evaluation. Important items to consider are the following:

1. Raw materials (availability, quantity, quality, cost)
2. Thermodynamics and kinetics of chemical reactions involved (equilibrium, yields, rates, optimum conditions)
3. Facilities and equipment available at present
4. Facilities and equipment which must be purchased
5. Estimation of production costs and total investment
6. Profits (probable and optimum, per pound of product and per year, return on investment)
7. Materials of construction
8. Safety considerations
9. Markets (present and future supply and demand, present uses, new uses, present buying habits, price range for products and by-products, character, location, and number of possible customers)
10. Competition (overall production statistics, comparison of various manufacturing processes, product specifications of competitors)
11. Properties of products (chemical and physical properties, specifications, impurities, effects of storage)
12. Sales and service (method of selling and distributing, advertising required, technical services required)
13. Shipping restrictions and containers
14. Plant location
15. Patent situation and legal restrictions

Process Development

Program to obtain additional data as needed by indications from the feasibility survey.

1. Look at all possible manufacturing processes
2. Establish bases for design in order to eliminate flowsheet options (eg. product specifications, fraction of the year that plant will be in operation, temperature of the cooling water, available steam pressures, fuel used, value of the by-products, etc.)
3. Prepare simplified flow diagrams showing the processes and deciding on the unit operations involved.

   Note: preliminary material balances at this point may eliminate some of the alternative cases.
4. Select equipment using material and energy balances
5. Preform an economic evaluation

32 Factors in process comparison

1. Technical factors
   (eg. Batch vs. Continuous, process flexibility, etc.)
2. Raw materials
   (eg. availability, handling problems)
3. Waste products and by-products
   (eg. amount, environmental)
4. Equipment
5. Plant location
   (eg. Climate, transportation, labor)
6. Costs
7. Time factor
   (completion deadline, value of money)
8. Process considerations
   (eg. technology available, consistency of product within company)

 General Design Considerations:

I Plant location
1. Raw Materials
2. Markets
3 Energy availability
4. Climate
5. Transportation facilities
6. Water supply
7. Waste disposal
8. Labor supply
9. Taxation and legal restrictions
10. Site characteristics
11. Flood and fire protection
12. Community factors

II Plant Layout (can be important in construction and manufacturing costs)

III Plant Operation and Control
1. Instrumentation
2. Maintenance

IV Utilities

V Structural Design (foundation for the equipment and vibrating machinery)

VI Storage

VII Materials Handling

VIII Waste Disposal

IX Federal and State Environmental Regulations

X Air pollution abatement
1. Particulate removal
2. Noxious gas removal

XI Water Pollution Abatement
1. Physical Treatment
2. Chemical Treatment
3. Biological Treatment

XII Solid Waste Disposal
1. Recycling and chemical conversion
2. Incineration
3. Pyrolysis (w/o O_2)
4. Land fill

XIV Thermal Pollution Control

XV Health and Safety
1. Safety Regulations
2. Chemical Hazards
3. Fire and Explosion Hazards
4. Personnel Safety
5. Noise Abatement

XVI Patents
1. Patentable Inventions
2. Patent Applications
3. Foreign Patents
4. Interferences
5. Infringement
6. Assignment of Patent Rights

p 302 ch. 9 Profitability

p 304 rate of return $= \frac{\text{profit (annual)}}{\text{investment cost}} 100\%$

eg. process cost \$1,000,000 and the annual profit is \$50,000

rate of return $= \frac{50{,}000 (100\%)}{1{,}000{,}000} = 5\%$

Note: Treasury bonds pay ≈ 7%; thus ror should be > 7%

discounted cash flow (takes into account time value of money)

apply discount factor $d_n = \frac{1}{(i+1)^n}$ to find future value of profit

i = rate of return
n = # years

ex.
initial fixed capital investment = \$100,000
working capital investment = \$ 10,000
service life = 5 years
salvage value at end of service life = \$10,000

Year	predicted cash flow
0	(110,000)
1	30,000
2	31,000
3	36,000
4	40,000
5	43,000

solve iteratively for i

$$(30{,}000)(1+i)^4 + (31{,}000)(1+i)^3 + (36{,}000)(1+i)^2 + (40{,}000)(1+i) + 43{,}000 = S$$

$$S = (110{,}000)(1+i)^5 - 10{,}000 - 10{,}000$$

<u>Net present worth</u> find present value of cash flows and subtract the initial investment

<u>capitalized costs</u> useful for comparing alternatives $= \dfrac{C_R(1+i)^n}{(1+i)^n - 1} + V_s$

C_R = replacement cost
V_s = salvage value

$$\underset{\text{(no interest)}}{\text{payout period}} = \frac{\text{depreciable fixed-capital investment}}{\text{avg. profit/yr + avg. depreciation/yr}}$$

= minimum length of time theoretically necessary to recover the original capital investment

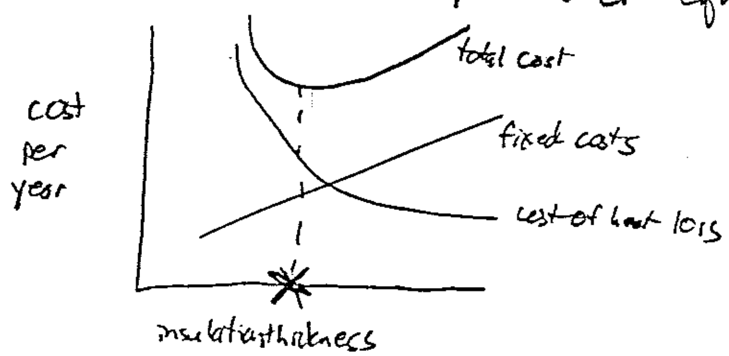
<u>continuous interest</u>: replace $(1+i)^n$ with e^{rn}

eg. $d_n = \dfrac{1}{e^{rn}}$

p357 ch. 10 <u>Optimum Design and Design Strategy</u>

take minimum of cost vs. parameter equation or graph

eg.

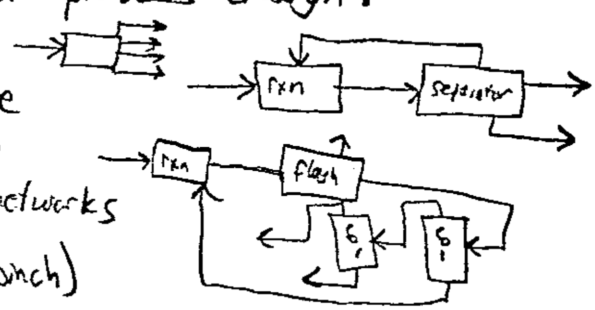


(linearize non-linear equations)

Procedure for process design:

1. input-output
2. recycle structure
3. separation system
4. heat-exchanger networks

(design above the pinch)



Equipment costs from Douglas Conceptual Design of Chemical Processes

327 **Heat exchangers:** $C_A = C_{A,BC}\left(\frac{A}{A_{BC}}\right)^{0.65}$

$\boxed{BC = \text{Base case}}$

$$Q = F C_p \Delta t = U A \Delta T_{LM}$$

Isothermal plug-flow reactor: $V = \frac{F}{k\rho} \ln \frac{1}{1-x}$ (first order isothermal)

$$C_R = C_{R,BC}\left(\frac{V_R}{V_{R,BC}}\right)^{0.63}$$

Furnaces:

$$C_F = C_{F,BC}\left(\frac{Q_F}{Q_{F,BC}}\right)^{0.78}$$

Compressors: $C_c = C_{c,BC}\left(\frac{B_{hp}}{B_{hp,BC}}\right)^{0.93}$ B_{hp} = power/efficiency

$$\text{Power} = \frac{3.03\times10^{-5}}{\gamma}\,\frac{P_{in} F_v}{60\rho}\left[\left(\frac{P_{in}}{P_{out}}\right)^{\gamma} - 1\right]$$

$$\gamma = \left(\frac{C_p}{C_v} - 1\right)\frac{C_p}{C_v}$$

(isentropic compression of an ideal gas)

Distillation Columns: $C_{sh} = C_{sh,BC}\left(\frac{N}{N_{BC}}\right)^{0.862}\left(\frac{D_{ia}}{D_{ia,BC}}\right)^{1.066}$ N = # trays

additional data
From Gutherie's