REVIEWER
FOR
CHEMICAL ENGINEERING
LICENSURE
EXAMINATION

3rd Edition

Solutions Manual

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If some of the values are different, then these are brought by rounding off. As much as possible, values are not rounded-off to obtain the most possible accurate answers.

I. Physical and Chemical Principles

A. General Inorganic Chemistry

4. For Zn^{2+}, atomic number = 30, atomic mass = 65.38 (~65),
Number of protons = 30; neutrons = 65-30 = 35; electrons = 30 – 2 = 28
e^- + proton + neutron = 30 + 35 + 28 = 93

6. The Balmer series or Balmer lines in atomic physics, is the designation of one of a set of six different named series describing the spectral line emissions of the hydrogen atom (Wikipedia, 2014).

$\lambda = (\frac{n^2}{n^2 - m^2})(R_\infty/4)$; for m = 2 as n → ∞

Balmer series = $1/\lambda = \frac{\infty}{\infty}(R_\infty/4)$ = 10973731.57 m/4 = 27434.3289 cm^{-1}

7. Named after the American physicist Frederick Sumner Brackett who first observed the spectral lines in 1922 (Wikipedia, 2014).

Brackett series = $(\frac{1}{m^2} - \frac{1}{n^2})(R_\infty)$; m = 4 as n → ∞ = 10973731.57 m/16 = 6858.5822 cm^{-1}

10. Minimum wavelength of light for work functions (de Broglie wavelength)
For Φ = 2.90 eV (J/C of electron)

$$\lambda = \frac{hc_o}{\phi e} = \frac{(6.6261\ x\ 10^{-34})(299792458)}{(2.90)(1.6022\ x\ 10^{-19})} = 427.5317\text{ nm}$$

11. For Φ = 5.00 eV

$$\lambda = \frac{hc_o}{\phi e} = \frac{(6.6261\ x\ 10^{-34})(299792458)}{(5.00)(1.6022\ x\ 10^{-19})} = 247.9584\text{ nm}$$

13. Work function and kinetic energy
Rb Φ = 2.16 eV; λ = 350 nm of light wavelength.
$E_{photon} = \Phi + E_k = hv = hc_o/\lambda$; $E_k = hc_o/\lambda - \Phi$
$E_K = \frac{(6.6261\ x\ 10^{-34})(299792458)}{350\ X\ 10^{-9}} - 2.16(1.6022\ x\ 10^{-19})$
$E_K = 2.1667 \times 10^{-19}$ J
$E_k = (m_e v^2)/2$ = 689721.8665 m/s ~ 7.00×10^5 m/s

14. for n =2 and m_s = -1/2. For l=0 and l = 1, it is composed of 3 counter-clockwise at p orbital and 1 at the s-orbital = 4 electrons

15. Cl = 35.45 composed of Cl-35 and Cl-37
35.45 = 37(x) + 35(1-x) where x is the fraction of Cl-37
x= 0.225; Cl-35 is 77.5 % in abundance.

17. If l = 0, m_l should be = 0.

18. Outermost shell is at n = 4; taking the electrons at the outermost shell of $4s^2$ and $4p^3$, 2 + 3=5.

31. T = 1600 °C; $Br_{2(g)} \rightarrow 2Br_{(g)}$
nBr_2 = 1.05 moles ; Tv = 2 L; α = 0.025
$[Br_2]$ = 1.05/2 = 0.525 M

$K_c = \{([Br]^2)/Br_2\}_{eq} = 1.3462 \times 10^{-3}$ M
$K_p = K_c(RT)^{\Sigma v}$
$K_p = 1.3462 \times 10^{-3}(0.08206 \times 1873.15)^{2-1}$ = 0.2069 atm

$Br_{2(g)}$	$2Br_{(g)}$
0.525	0
0.525(1-α)	0.525x2α
0.511875 M	0.02625 M

36. $VP_{H_2O}°$ = 23.756 torr (25°C); m_{solute} = 18.913 g; $m_{solvent}$ = 36 g H_2O; VP_{soln} = 20.234 torr
MW solute = ?

$VP_{soln} = VP_{H_2O}^{\circ}X_{solvent}$
20.234 = 23.756(x); x = 0.8517 therefore, the mole fraction of the solute is 0.1483
36 g/ 18.02g/mole = 1.9978 mole solvent; 0.8517 = 1.9978/(1.9978 + n_{solute})
n_{solute} = 0.3479 moles
MW = 18.913 g/ 0.3479 moles = 54.3693 g/mol ~ 56 g/mol

37. 30% wt urea in water.
$\Delta T = Kfmi$
Since urea is non-electrolyte, i = 1;
m = (30 g urea/60.07 g/mol)/70 g H_2O/1000g/kg
m = 7.1345 mol/kg
$\Delta T = (7.3145\ m)\left(1.86^{\circ}\frac{C}{m}\right)(1) = 13.2702\ C^{\circ}$; T_{soln} = 0-13.2702 = -13.2702°C

38. m = 0.205 m with respect to urea
200 g of solution is diluted with 250 g of water
First find the number of moles of urea present in a 200 g solution.
0.205/1000 g = (x/60.07)/(200 – x); x = 2.4329 g of urea
m' = (2.4329 g/60.07 g/mole)/(200 g – 2.4329 g + 250 g)/1000g/kg
m' = 0.09049 m
$Tf = 0℃ - (0.09049\ m)\left(1.86^{\circ}\frac{C}{m}\right)(1)$ = -0.1683 °C

39. π = 38 mm Hg (at 273.15 K)
ΔTb =?
Π = MRT
M = (38mm Hg/760 mm Hg/1 atm)/(0.08206 atm-L/mol-K)(273.15 K)
M = 2.2307×10^{-3} M
$\Delta Tb = Kbmi\ assuming\ that\ m \sim M; = \left(0.512\ C^{\circ}\frac{}{m}\right)(2.2307 \times 10^{-3} m)(1) = 0.001142\ C^{\circ}$

40. Ra-226 -----→ He + $^{222}_{86}$Rn (α emission atomic mass decreased by 4, atomic number by 2)

41. Half-life is 29 years. Fraction (x) remained after 100 years = ?
Since half-life exhibits first order reactions,
k = ln2/$t_{1/2}$ = ln2/29 = 0.0239 $years^{-1}$
ln|Ao| - ln|A| = kt = ln|1| - ln|x| = 0.0239(100)
x = 0.0916 remains

42. Another first order reaction:
ln|1| - ln|0.01| = 50(k)
k = 0.092103 $years^{-1}$
$t_{1/2}$ = ln2/k = 7.5257 years

43. Ra-226 half-life = 1600 years
α emission; t= 10 mins; 10 mg sample of Ra-226. 1 year = 365 days.
Since it still follows first order reaction, k = ln2/1600 = 4.3322×10^{-4} $years^{-1}$
For t = 10 mins, 10/(60)(24)(365) = 1.9026×10^{-5} years thus,
kt = 8.24233×10^{-9} disintegration
for 10 mg, 10 mg/(226)(1000 mg/g) = 4.4248×10^{-5} moles = 2.6646×10^{19} particles
(2.6646×10^{19} particles)(8.24233×10^{-9} disintegration) = 2.1963×10^{11} disintegrations

44. Activity = number of disintegrations per second
1Ci = 3.7×10^{10} disintegration/atom-sec
k = ln2/(1600 x 365 x 24 x 3600) = 1.3737×10^{-11} sec^{-1}
kn = (1.3737×10^{-11})(2.6646×10^{19}) = 366041979.3 particles/s
Activity = 366041979.3 dps/3.7×10^{10} dps/Ci = 9.8930 Ci

46. First order reaction; K-40 decayed to Ar-40 $t_{1/2} = 1.27\times10^9$ years. Age of rock = ?
mAr/mK = 4.

k = ln2/1.27x10^9 years = 5.4579 x 10^{-10}/year
ln|K+Ar| – ln|K| = kt = ln|4K + K| - ln|K| = t(5.4579 x 10^{-10}/year)
cancel K as ln|5| = t(5.4579 x 10^{-10}/year); t = 2.9488 x10^9 years.

49. For C-13 (13.003355), what is the binding energy in MeV?
Using $E_{bind} = \Delta mC_o^2$, For C-13 with number of protons = 12 and neutron = 1;
12(1.007276466 amu) = 12.08731759 (from $(m_p)(N_A)(1000)$)
1(1.008664915 amu) = 1.008664915 (from $(m_n)(N_A)(1000)$)
m’ = proton + neutron = 13.09598251
$E_{bind} = \Delta mC_o^2$ = (13.003355 - 13.09598251)$(299792458)^2$ = -8.3249 x 10^{15} amu m^2/s^2
= (-8.3249 x 10^{15} amu m^2/s^2)/(6.022x10^{23} amu/g)(1000g/kg) = -1.3824 x10^{-11} J
$E_{bind/nucleon}$ = 1.3824 x10^{-11} J/13 = (1.0634 x 10^{-12} J/nucleon)
= (1.0634 x 10^{-12} J/nucleon)/(1.602176 x10^{-19} J/eV) = 6.6372 MeV ~ 7 MeV

50. Since it also follows the FO kinetics, 1g of Sr = 0.0111 moles and 0.953 g = 0.01058888 mol
Activity = ?
ln|0.0111111| - ln|0.01058888888| = k(2x365x24x3600); k = 7.632604 x 10^{-10} dps
initial particle concentration = (0.01111 x 6.02214179 x 10^{23}) = 6.6913 x 10^{21} particles
kn = (7.632604 x 10^{-10} dps)(6.6913 x 10^{21} particles) = 5.107182022 x10^{12} p-dps
Activity = 5.107182022 x10^{12} p-dps/3.7x10^{10} dps/Ci = 138.0319 Ci ~ 140 Ci

B. Organic Chemistry

4. Unsaturated must be an alkene/alkyne. Ans: C_5H_{10}

6. C_1-C_4 is a gas at room temperature. Ans: propane

7. The process is a coupling type by Wurtz synthesis. It should've been 2 moles of ethyl bromide. Ans: butane

8. Note that the more branched an alkane is, the more soluble it is in water. Ans. 3

9. Ans: Alcoholic KOH. It is a reagent in reaction of an alkyl halide to produce an alkene.

10. In such process, elemental chlorine can attach to the secondary carbon or the first carbon. Ans: 2

12. A cis-3-hexene is simply an alkene of hexane. Cycloalkane = alkene of the same number of carbons since they have the same atomic mass. Ans: cyclohexane

13. Number 1 cannot have a cis-trans isomer since one side of the geometric orientation would produce the same substituent (i.e. H). Ans: both 2 and 3

17. Ans: Br_2/ uv or light. The reaction is evident only for alkanes and/or alkynes.

19. "Markovnikov's Rule: The rule states that with the addition of a protic acid HX to an unsymmetrical alkene, the acid hydrogen (H) becomes attached to the carbon with fewer alkyl substituents, and the halide (X) group becomes attached to the carbon with more alkyl substituents (Wikipedia, 2014)."

"Zaitsev Rule: "The alkene formed in greatest amount is the one that corresponds to removal of the hydrogen from the β-carbon having the fewest hydrogen substituents." (Wikipedia, 2014)

Ans: Morkovnikov's Rule

20. Reaction must produce an anti-markovnikov orientation, thus hydroboration-oxidation is the appropriate process. Ans: Hydroboration-oxidation

23. Geminal dihalide means that 2X is attached to same C of the functional group. Ans: Geminal dihalide

26. Answer should be none of these. Since it has 5 skeletal Carbon chain, the proper name is 4-methyl-pent-2-ene.

27. H of terminal alkynes is more acidic than other alkynes since the compound contain more s character. Ans: propyne

28. Using Huckel's Rule = 4n + 2 = π electrons;
Naphthalene π = 10 so n = 2. For benzene, π = 6; so n =1. For the next compound, n = -1/2. It is also not conjugated. Thus Ans: B

30. Ans: 3. These are ortho, para, and meta orientation.

35. Since 1° alcohol undergoes SN_2 reaction mechanism, Ans: 1-propanol.

37. Step 1 of the reaction mechanism of epoxides in acid-catalyzed cleavage produces diol in H^+. Ans: dihydric alcohol

40. Lucas Test – $ZnCl_2$ and HCl used to differentiate alcohols of low molecular weight.

Tollen’s Test – usually ammoniacal silver nitrate used to distinguish aldehydes or alpha-hydroxy ketones.

Fehling’s Test - is a chemical test used to differentiate between water-soluble carbohydrate and ketone functional groups, and as a test for monosaccharides. Ans: Lucas Test

57. Starting from R-O-O-R, it is hydrolyzed with water and acid to produce an acid.

In this process, hydrolysis of esters to produce an acid is carboxylic acid (X) and an unknown alcohol (Y).

Then, alcohol is oxidized with hot $KMnO_4$ to yield an acid X.

Since we know that X is a carboxylic acid, then Y is an aldehyde of 2 carbons which is acetaldehyde. Knowing X as carboxylic acid and Y as acetaldehyde, the ester have 2 carbons, one with doubly bonded to O and another 2 carbons, one which is singly bonded to O. Thus, the ester is ethyl ethanoate.

C. Analytical Chemistry

4. Given the condition that the normality as a reducing agent (N_{RA}) is thrice the normality as an acid (N_A), the expression yields to the assumption of additive species in a 1-L solution.

For $N_{RA,}$

$N_{RA} = (n_T)(f[x,y])/1\text{-L}$ {amount of component multiplied by equivalent weight (f) for component X ($Na_2C_2O_4$) and Y ($KHC_2O_4 \cdot H_2C_2O_4$)}.

$N_{RA} = (X)\frac{2}{134} + (Y)\frac{4}{218.2}$ [1]; for simplification, N_{RA} can be expressed to 1 N so that N_A = 3N.

*2 and 4 are the values of f for the component and can easily be observed from the number of + ions that appear during redox reaction. For a reducing agent, $H_2C_2O_4$ = 0 and O.N. = +6 (2 moles of Carbon based), and during oxidation, CO_2 is liberated and thus for CO_2, O.N. = +8. 8-6=2 for $H_2C_2O_4$. While, for the KHC_2O_4, the H^+ is just replaced with K^+ meaning, O.N. = 8-6 =2. 2+2 = 4 as a reducing agent. (Or simply by looking at the number of Carbon in the compound). For $Na_2C_2O_4$, $2Na^+$ gives the f=2.

$N_A = X(0) + Y\frac{3}{218.2}$ [2]

For an acid, the replaceable hydrogen for the first compound does not appear so it will be zero and for the second one, there are 3 moles of replaceable hydrogen.

Equating 1 and 2, setting N_{RA} =1 and N_A =3,

X = 72.73333 g; Y = 111.6667 g

Thus X/Y = 72.73333/111.66667 = 0.6513

6. MiVi = MfVf

Since a concentrated HCl is 12 Normal with f =1, the molarity is 12 molars.

(100)(0.955) = (12)(Vi)

Vi = 7.9583 mL; therefore, for the additional volume, 100-7.9583 = 92.0417 mL

8. Using the idea that in 100 g sample of $NaCl_{(aq)}$, there are 20g of NaCl and 80 g of water.
%wt/vol = ? Volume = 100g/1.145 g/mL = 87.3362 mL; Mass = (20g/87.3362 mL)x100% = 22.9000%

9. Molarity (M) = ?
For 20 g of NaCl, n = 20g/58.45g/mol = 0.3422 mole and using the above volume;
0.3422 mole/(87.3362 mL/1000 mL/L) = 3.9182 M

10. molality = ?

Using the same number of moles, 0.3422 mole and 80 g of solvent which is 0.08 kg of solvent, molality should be equal to 0.3422/0.08 = 4.2775 m

However, the problem assumed that the total mass of the solution was used resulting to 100 g of solvent which is equivalent to 0.1 kg. Thus 0.3422/0.1 = 3.422 m.

Still, the correct answer should be 4.2775 m.

12. m_{sample} = 1.5176 g; $CaC_2O_4 \cdot H_2O$ (146.11) precipitate = 0.8249 g.

% of CaO in the sample = ?

$$0.8249\frac{56.08}{146.11-18.02\ (because\ of\ evaporation\ of\ water\ upon\ ignition)}x\frac{100}{1.5176} = 23.7978\%$$

13. Mixture contains $FeCl_3$ and $AlCl_3$ which amount to 750.8 mg. After removal of chlorides, Fe_2O_3 and Al_2O_3, its oxides, weigh 351.3 mg. %Al = ?

Letting the amount of $FeCl_3$ as x and $AlCl_3$ as y,

x + y = 750.8 mg (1)

Letting the amounts of its oxides relate to the stoichiometric ratios,

$$\frac{\text{Fe2O3}}{\text{2FeCl3}}x + \frac{\text{Al2O3}}{\text{2AlCl3}} = 351.3\ mg\ (2)$$

Equating 1 and 2, x = 584.3735 mg; y =166.4265 mg

From the 166.4265 mg of sample, Al = $\frac{\text{m of AlCl3 x Al}}{\text{AlCl3}} = \frac{166.4265}{133.33}x26.98 = 33.6772\ mg\ of\ Al$

%Al = $\frac{33.6772\ mg}{750.8\ mg}\ x\ 100\% = 4.4855\%$

17. m_{ore} = ?

By using the relationship given, we derive the formula $(mMnO_2/ore)100 = 2\ Mn_3O_4$ and thus,

$m_{ore} = \frac{MW\ MnO_2}{2\ MW\ Mn_3O_4} x \frac{3}{1} = \frac{3\ x\ 86.94}{2\ x\ 228.82} x 100$ = 56.9924 mg

20. lowest pH

For 0.15 M Na_2SO_4 ($K_a = 1.2 \times 10^{-2}$): dissociation of the compound gives a 0.15 M SO_4^{-2}

Since the process is formation of OH^-, use K_b

$K_b = K_w/K_a = 8.3333 \times 10^{-2}$

$8.3333 \times 10^{-2} = x^2/(0.15-x)$; $x = 3.5355 \times 10^{-7}$ M

Thus pOH = $-\log(3.5355 \times 10^{-7}) = 6.4515$ and

pH = 14-6.4515 = 7.5485.

SO_4^{-2} +	H_2O↔	HSO_4^- +	OH^-
0.15		0	0
0.15-x		x	x

For strong acid, pH = $-\log|5.2 \times 10^{-8}| = 7.2840$

*This process is a direct determination of pH since HCl is a strong acid.

For 0.05 M NaCN, ($K_a = 6.2 \times 10^{-10}$): dissociation gives 0.05 M of CN^- for the reaction

$CN^- + H_2O \leftrightarrow HCN + OH^-$

Since the process is formation of OH^-, use K_b

$K_b = K_w/K_a = 1.6129 \times 10^{-5}$

$1.6129 \times 10^{-5} = x^2/(0.15-x)$; $x = 8.9000 \times 10^{-4}$ M

Thus pOH $=-\log|8.9000 \times 10^{-4}| = 3.0506$ and

pH = 14-3.0506 = 10.9494

CN^- +	H_2O↔	HCN +	OH^-
0.05		0	0
0.05-x		x	x

For 0.01 M of NH_4Cl ($K_a = 5.6 \times 10^{-10}$) dissociation gives 0.01 M of NH_4^+ for the reaction

$NH_4^+ + H_2O \leftrightarrow NH_3 + H_3O^+$

Since the process is formation of H_3O^+, use K_a

$K_a = 5.6 \times 10^{-10} = x^2/(0.01-x)$; $x = 2.3662 \times 10^{-6}$

Thus, pH = $-\log|2.3662 \times 10^{-6}| = 5.6260$

Therefore, the lowest pH is for 0.01 M of NH_4Cl which is pH = 5.6260.

NH_4^+ +	H_2O↔	NH_3 +	H_3O^+
0.01		0	0
0.01-x		x	x

22. [HCl] = 0.1025 M, $[NH_3]$ = 0.0956 (V_{NH3} = 15.64 mL); pH of solution = 9.00

For the reaction of NH_3 to HCl during a titration process,

$NH_3 + HCl \leftrightarrow NH_4Cl$

For NH_3, n = (0.0956)(15.64) = 1.4952 mmol

For HCl, = n = (0.1025)(x)

Since it gives us a pH of 9.00 which is basic, it is therefore enough to assume that HCl is the limiting reactant so that NH_3 will be left with something. Therefore the initial concentration of NH_4Cl is (0.1025x)/x+15.64

NH_3 +	HCl↔	NH_4Cl
1.4952	(0.1025)(x)	0
1.4952-(0.1025)x	0	(0.1025)x

For NH_4Cl compound, the NH_4^+ is also (0.1025x)/x+15.64 and therefore, the dissociation is

$$NH_4^+ + H_2O \leftrightarrow NH_3 + H_3O^+$$

Since we know that pH is 9.00 the $[H_3O^+]$ is $10^{-9} = 1 \times 10^{-9}$ M and since $y = n\ H_3O^+$, $[H_3O^+](x+15.64) = y$

$y = (1 \times 10^{-9})(x+15.64)$

Using K_a of NH_4^+ which is 5.6×10^{-10},

NH_4^+ +	H_2O ↔	NH_3 +	H_3O^+
(0.1025x)		1.4952-(0.1025)x	0
0.1025x - y		{1.4952-(0.1025)x} + y	y

$$K_a = \frac{[H_3O^+][NH_3]}{[NH_4^+]} = \frac{(1X10^{-9})(\frac{(1.4952-0.1025x)+(1x10^{-9})(x+15.64)}{x+15.64})}{\frac{0.1025x-(1x10^{-9})(x+15.64)}{x+15.64}} = \frac{(1X10^{-9})((1.4952-0.1025x)+(1x10^{-9})(x+15.64)}{(0.1025x-(1x10^{-9})(x+15.64)};$$

x = 9.3508 mL

For shortcut, using Henderson-Hasslebalch equation: pH = -log|K_a| + log|$\frac{basic\ component}{acidic\ component}$|

9.00 = -log|5.6 x 10^{-10}| + log| $\frac{1.4952-0.1025x}{0.1025x}$| = 9.3508 mL.

24. 1L of 0.125 F of NH_3.

To determine the amount of [OH^-] present, the reaction must be checked:

$NH_3 + H_2O \longrightarrow OH^- + NH_4^+$

And since 0.125 F = 0.125 M,

Using K_b as 1.785 x 10^{-5} for NH_4^+,

[X] = [OH^-] = 1.4851 X 10^{-3} M

The initial concentration of the sample is 1.4851 x 10^{-3} M/0.001 = 1.4851 M

n [OH^-] = n [NH_4^+] = 1.4851 moles

using 1 to 1 ratio for NH_4Cl,

m NH_4Cl =

= 1.4851 molesx $\frac{53.45\ g/mol}{1\ mole}$ = 79.3804 g.

NH_3 +	H_2O ↔	OH^- +	NH_4^+
0.125 M		0	0
0.125-x		x	x

27. KHP = potassium hydrogen phthalate ($C_8H_5KO_4$) = 204.23 g/mol

Titration leads to: NaOH + KHP $\longrightarrow$ H_2O + KNaP

$$M = \frac{\frac{0.2615g}{204.23g/mol}}{12.25\ mL/\frac{1000m\ L}{1L}} = 0.1045\ M.$$

29. The process is standardization against KHP = 1.431 g.

During this process, 1.431/204.23 = 7.0068 x10^{-3} moles of KHP reacts.

Total amount of NaOH for titration is (35.50 mL)(10.75 mg/mL) = 381.625 mg.

n NaOH = 381.625 mg/40 mg/mmol = 9.540625 mmol = 9.540625 x 10^{-3} moles.

During back titration, (35.50-8.25 mL)(10.75 mg/mL) = 292.9375 mg = 7.3234 x 10^{-3} mole represents the amount of NaOH used to reach the equivalence point.

Thus: the NaOH itself is represented by nNaOH-(nNaOH$_{eq}$ – nKHP) = 9.540625 x 10^{-3} – (7.3234 x10^{-3} – 7.0068 x 10^{-3}) = 9.224025 x 10^{-3} moles.

$$[NaOH] = \frac{9.224025\ X\ 10^{-3}}{35.5\frac{mL}{1000mL}/1L} = 0.2598\ M.$$

31. m_{sample} = 0.2055 g; for the reaction during titration process:

$CaCO_3 + 2HCl \leftrightarrow CaCl_2 + H_2CO_3$ thus for every mole of HCl, there is one half mole of the ore. (27.18)(0.712)/1 = 1.935216 mmoles and back titrating, 1.935216 – (5.44)(0.0869) = 1.46248 mmoles of HCl used to titrate the ore. Since one half mole of HCl is equivalent to one mole of the ore, n$CaCO_3$ = 1.46248/2 = 0.73124 mmol.

(0.73124 mmol)(100mg/mmol/1000mg/g) = 0.073124 g.

Thus, %$CaCO_3$ = 0.073124/0.2055 x 100% = 35.5835%

34. For sample containing $NaHCO_3$ only, the V_{o-Ph} ~ 0.00 and thus, for V_{o-MR} = 6.19,

V_{Ph-MR} = 6.19-0.01 = 6.18 mL

% purity = (6.18 mL)(0.1025 M)(84.01 mg/mmol) = $\frac{53.2161\ mg}{500\ mg}$ x 100% = 10.6532%

35. For this condition, $V_{o-Ph} > V_{Ph-MR}$, among the data, the last one is the only one to satisfy the condition (to get V_{Ph-MR} subtract V_{0-MR} to V_{0-Ph}). For data 5, V_{Ph-MR} = 3.41 which is less than V_{0-Ph}.

n NaOH = (V_{o-Ph} - V_{Ph-MR})M = (5.63-3.41)(0.1025) = 0.22755 mmol; m NaOH = 9.102 mg

%NaOH = (9.102 mg/500 mg) x 100% = 1.8204%

37. Since the process is a Kjeldahl method, the reaction for ammonium ion is:

$NH_3 + H_3BO_3 \longrightarrow NH_4^+ + H_2BO_3^-$

For the amount of the boric acid used, 250 mL was used for liberating ammonia. This is not included since the reaction only needs the amount of borate which can be titrated with the amount of HCl.

$nHCl = nNH_3$

(37.25 mL)(0.3122 M HCl) = 11.62945 mmol of HCl = mmol of NH_3

For a mole of NH_3, there is one mole of Nitrogen, thus, (11.62945 mmol)(14.01 mg/mmol) = 162.8123 mg of N

Using the factor for meat 6.25, (162.8123 mg)(6.25) = 1017.576875 mg = 1.01757 protein

% protein = $\frac{1.01757g}{7.279\ g}x100\% = 13.9796\%$

39. m_{sample} = 1.500 g impure $AlCl_3$

V_{used} = 45.32 mL of 0.1000 M of $AgNO_3$ using K_2CrO_4 as indicator.

% $AlCl_3$ = ?

The reaction: $AlCl_3 + 3AgNO_3 \longrightarrow Al(NO_3)_3 + 3AgCl$

$\%AlCl_3 = \frac{m\ AlCl3}{m\ of\ impure\ AlCl3}x100\%$

$$= (45.32\ mL)(0.1000M)x\frac{1\ mmol\ AlCl3}{3\ mmol\ of AgNO3}x\frac{133.33\ mg}{1\ mmol\ AlCl3}x\frac{1}{1000\frac{mg}{g}x1.50\ g}x100\% = 13.42781\%$$

41. Represent LiBr (86.845) as x and $BaBr_2$ (297.22) as y. Relate equations using Volhard Method.

x + y = 800 mg (1)

For the direct titration:

$AgNO_3 + LiBr \longrightarrow AgBr + LiNO_3$

$2AgNO_3 + BaBr_2 \longrightarrow 2AgBr + Ba(NO_3)_2$

For the back titration:

$KSCN + LiBr \longrightarrow KBr + LiSCN$

$2KSCN + BaBr_2 \longrightarrow 2KBr_2 + Ba(SCN)_2$

The amount of $AgNO_3$ used is expressed as (50 mL)(0.1879 M) – (8.76 mL)(0.3179 M) = 6.610196 mmol since the stoichiometric ratio for $AgNO_3$ and KSCN is 1. Express the equation in terms of x and y to relate it to $AgNO_3$ and/or KSCN.

$\frac{X}{86.845} + \frac{2y}{297.22}$ = 6.610196 (2)

Equating 1 and 2, x = m LiBr = 256.3818 mg; y = m $BaBr_2$ = 543.6181671 mg.

% $BaBr_2$ = $\frac{543.6181671}{800}x\ 100\% = 67.9522\%$

42. The process is a complex formation titration. Using Liebig Method,

$2CN^- + Ag^+ \longrightarrow Ag(CN)_2^-$. Therefore, for permanent faint turbidity:

$Ag(CN)^-_2 + Ag^+ \longrightarrow Ag[Ag(CN)_2]_{(s)}$

(23.50 mL)(0.1255 M) = |2.94925 mmol $AgNO_3$|/(1 mmol $AgNO_3$/1 mmol $Ag(CN)_2$)

= 2.94925 mmol $Ag(CN)_2$

2.94925 mmol $Ag(CN)_2$ X $\frac{2\ mmol\ CN^{-1}}{1\ mmol\ Ag(CN)2}$ = 5.8985 mmol CN^- X $\frac{26.02\ mg/mmol}{1\ mmol\ CN^{-1}}$ =

153.47897 mg CN^-; $\%CN^{--}$ = $\frac{153.47897}{500}X100\% = 30.6958\%$

44. The process is a complex formation titration. Using the determination of nickel,

$Ni(NH_3)_6^{+3} + 4CN^- + 6H_2O \longrightarrow Ni(CN)_4^- + 6NH_4OH$ (1)

$2CN^- + Ag^+ \longrightarrow Ag(CN)_2^-$ (2)

For the amount of cyanide ion in the alloy,

(50 mL)(0.1075 M) – (2.25 mL)($\frac{0.00925\ M}{2}$) = 5.3646 mmol of CN^-

In the above reaction (1), there are 4 moles of CN^- for every Ni ion. Thus, nNi = ¼(nCN^-)

n Ni = (1.3411 mmol Ni)(58.69 mg/mmol) = 78.7120 mg of Ni
% Ni = (78.7120 mg/ 750.25 mg) x 100% = 10.4914%
The problem however is a 750.25 g alloy. This should be corrected to 750.25 mg.

46. EDTA solution
Vsample = 2 L; $mCaCO_3$ = 0.5063 g and Vconsumed = 28.50 mL;
V_{EDTA} = 35.57 mL
Amount of $CaCO_3$ in the EDTA solution = $\frac{0.5063\ g\ CaCO3}{28.50\ mL\ CaCO3} x \frac{35.57\ ml\ EDTA}{VEDTA/VCaCO3}$ = 0.63189 g $CaCO_3$
ppm $CaCO_3$ = 0.63189 g/2 L of solution = 0.315948964 g/L = 315.9490 ppm (mg/L)

48. EDTA Solution
Amount of sample = (35.00 mL)(0.1022 M) – (6.79 mL)(0.2467 M) = 1.901907 mmol of $BaCl_2$.
The reaction: $BaCl_2 + Na_2SO_4 \longrightarrow BaSO_4 + 2NaCl$. Thus for every sodium sulfate, there is one mole of $BaCl_2$ to precipitate the sulfate.
% purity = 1.901907 mmol of $BaCl_2$ $x \frac{1\ mmol\ of\ Na2SO4}{1\ mmol\ BaCl2} x \frac{142.04}{1\ mmol\ Na2SO4} x100\% = 90.0490\%$

50. Standard Hydrogen Electrode (SHE) is given by: $2H^+ + 2e^{--} \longrightarrow H_{2(g)}$.
$\varepsilon_{cell} = \varepsilon° - \frac{RT}{nF} \ln|K|$; n =2 for 2 electrons where K is the equilibrium expression.
For pH = 7, $[H^+] = 1X10^{-7}$ M and for P_T = 1 bar.
$Kc = \frac{1/2(X\alpha)}{X(1-\alpha)}$; = = $\frac{1}{(1x\ 10^{-7})^2}$
$\varepsilon_{cell} = \varepsilon° - \frac{RT}{nF} \ln|K = 0 - \frac{8.3145(273.15+25)}{2(96485.3399)} \ln|1x10^{-14}|$
ε_{cell} = -0.4141 V

$2H^+$	$\rightarrow$	H_2
X		0
X(1-α)		1/2Xα

52. The titration is an oxidation-reduction titration.
Against $Na_2C_2O_4$, $C_2O_4^{-2} \longrightarrow 2CO_2 + 2e^-$
And in an acidic medium: $MnO_4^- + 8H^+ + 5e^- \longrightarrow Mn^{+2} + 4H_2O$
Adding two equations: $5C_2O_4^{-2} + 2MnO_4^- + 16H^+ \longrightarrow 10CO_2 + 8H_2O$
$[KMnO_4] = \frac{1.356\ g\ Na2C2O4}{134\ g/mol} x \frac{1\ mol\ C2O4}{1\ mol\ Na2C2O4} x \frac{2\ moles\ MnO4}{5\ moles\ C2O4} x \frac{1\ mole\ KMnO4}{1\ mole\ MnO4} x \frac{1000\ ml/L}{25.1\ mL} = 0.1613\ M$

54. Process involved is a dichromate process.
$Cr_2O_7^{-2} + 6e^- \longrightarrow 2Cr^{+3}$
$Fe_3O_4 \longrightarrow Fe^{+3} + 3e^- + 2FeO + O_2$
Adding the two equations, the expression becomes:
$Cr_2O_7^{-2} + 2Fe_3O_4 \longrightarrow 2Cr^{+3} + 2Fe^{+3} + 4FeO + 2O_2$
(52.36 mL)(0.01436 M) = 0.7519 mmol of $K_2Cr_2O_7$, the stoichiometric balance:
0.7519 mmol of $K_2Cr_2O_7$ x $\frac{1\ mole\ of\ Cr2O7}{1\ mmol\ of\ K2Cr2O7} x \frac{2\ mole\ of\ Fe3O4}{1\ mmol\ of\ Cr2O7} x \frac{231.55g}{mol} Fe_3O_4 = 348.20489\ g$
$\%\ Fe_3O_4 = \frac{348.20489}{385.6} x100\% = 90.3021\ \%$

55. Process involved is an Iodometric titration.
$2S_2O_3^{-2} + I_2 \longrightarrow S_4O_6^{-2} + 2I^-$
$I_2 + 2e^- \longrightarrow 2I^-$
$MnO_2 \longrightarrow Mn^{+2} + O_2 + 2e^-$
Adding the equations, $MnO_2 + 2S_2O_3^{-2} \longrightarrow S_4O_6^{-2} + 2I^-$
(46.24 mL)(0.1105 M $Na_2S_2O_3$) = 5.10952 mmol of $Na_2S_2O_3$
5.10952 mmol of $Na_2S_2O_3$ x $\frac{1\ mmol\ of\ S2O3}{1mmol\ of\ Na2S2O3} x \frac{1\ mmol\ of\ MnO2}{2\ mmol\ S2O3} x \frac{86.94\ mg}{1mmol\ of\ MnO2} = 222.1108\ mg$
% MnO_2 = $\frac{222.1108\ mg}{240.0\ mg} x100\% = 92.5462\ \%$

57. The process falls under acidic Permanganate process against a ferrous solution.

$MnO_4^- + 8H^+ + 5e^- \longrightarrow Mn^{+2} + 4H_2O$ (1)

$Fe^{2+} \longrightarrow Fe^{+3} + e^-$ (2)

Net reaction: $MnO_4^- + 8H^+ + 5Fe^{2+} \longrightarrow Fe^{+3} + Mn^{+2} + 4H_2O$

(25 mL)(0.00514 M) – (14.97 mL$x \frac{0.01678\ mmol/mL}{1\text{mmol of MnO4}} x \frac{1\ mmol\ of\ MnO4}{5\ mmol\ of\ Fe}$) = 0.078260 mmol of MnO_4^-.

Application involves the nitrate ions,

$NO_2^- \longrightarrow NO_3^- + 2e^-$ (3)

Net reaction for 1 and 3: $2MnO_4^- + 16H^+ + 5NO_2^- \longrightarrow 2Mn^{+2} + 8H_2O + 5NO_3^-$.

0.078260 mmol of MnO_4^- x $\frac{5\ mmol\ NO2}{2\text{mmol of MnO4}} x \frac{46.01\ mg/mmol}{1\text{mmol of NO2}} = 9.00186\ mg$

ppm NO_2^- = 9.00186 mg/($\frac{10\ g}{1000\ g/kg}$) = 900.186 ppm (mg/kg)

59. Winkler method is a process of determining oxygen by fixed addition of Mn(II) under basic condition.

$Mn^{2+} + 2OH^- \longrightarrow Mn(OH)_2$

$2Mn(OH)_2 + ½(O_2) + H_2O \longrightarrow 2MnO(OH)_2$

$2Mn(OH)_3 + 2I^- + 6H^+ \longrightarrow 2Mn^{+2} + I_2 + 6H_2O$

$I_2 + I^- \longrightarrow I_3^-$

$I_3^- + 2S_2O_3^{-2} \longrightarrow 3I^- + S_4O_6^{-2}$

(7.52 mL)(0.0124 M $Na_2S_2O_3$) = 0.093248 mmol of $Na_2S_2O_3$ = 0.093248 mmol of $S_2O_3^{-2}$.

0.093248 mmol of $S_2O_3^{-2}$ x $\frac{1\ mmol\ I_2}{2\ mmol\ S2O3} x \frac{2\ Mn^{+2}}{1\ mmol\ I_2} x \frac{2\ Mn(OH)_2}{2\ Mn^{+2}} x \frac{1/2(O_2)}{2\ Mn(OH)_2} x \frac{32\ mg}{1\ mmol\ O_2} = 0.745984\ mg$

ppm of O_2 = 0.745984 mg/(100 mL/1000 mL/L) = 7.45984 ppm (mg/L).

60. Using Beer's Law: A = εbc,

Let C_{Co} = concentration of Cobalt and C_{Ni} = concentration of Nickel.

A = εbc(Co) + εbc(Ni) [double-component system]

0.815 = (36400 /M-cm)(1 cm)(C_{Co}) + (5520/M-cm)(1 cm)(C_{Ni}) [1]

0.314 = (1240/M-cm)(1 cm)(C_{Co}) + (17500/M-cm)(1 cm)(C_{Ni}) [2]

Equating 1 and 2,

$C_{Co} = 1.9883 \times 10^{-5}$ M ; $C_{Ni} = 1.65340 \times 10^{-5}$

(1.9883×10^{-5} mmol/mL)(50 mL) = (9.9415×10^{-4} mmol)(58.93 mg/mmol) = 0.058585 mg Co

ppm = (0.058585 mg Co)/(25mL/1000 mL/L) = 2.3434 ppm (mg/L).

The concentration is based on the aliquot. However, with respect to the solution, the amount of Co is 0.058585 mg/(500mg/1000mg/kg) = 0.11717 ppm (mg/kg).

D. Physical Chemistry

2. For ρ = 1.0628 g/L; T= 30°C; 740 torr,
ρRT = PM
M= (1.0628 g/L)(0.08206 atm-mol/L-K)(30 + 273.15 K)/(740/760 atm)
M = 27.15329 g/mol
Let x = fraction first element, y = (1-x) = fraction of second element.
The equation shall obey $xMW_1 + yMW_2 = 27.15329$ [1]
From inspection, elements with MW whose one is above the average while the other one is below.
Ans: Ne(20) – Ar(40)

3. Substitution from [1], x = 0.3577; y = 0.64233. Fraction of lighter element = y = 0.64233

5. 2.875 g $CaCO_3$/100 g = 0.02875 mol $CaCO_3$ = 0.02875 mol of CO_2. From Dalton's Law of Partial Pressure, $P_T = PH_2O + PCO_2$; 740 mmHg = 23.756 mmHg + PCO_2; PCO_2 = 716.244 mmHg.
PV = nRT; V = (0.02875 mol)(0.08206 atm-L/mol-K)(25+273.15 K)/(716.244/760)atm = 0.7464 L.

7. From the table, m CO-CO_2 mixture = 37.5265 – 37.2564 = 0.2701 g;
m H_2O = 215.8819 – 37.2564 = 178.6255 g.
On the assumption that ρ = 1g/mL for H_2O; V of the dry bulb = 178.6255 mL. PV = nRT;
n = PV/RT = (1)(178.6255/1000)/[(0.08206)(25+273.15)]
n = 7.3009×10^{-3} mol
MW = 0.2701 g/7.3009×10^{-3} mol = 36.9954 g/mol.

8. nT = nCO_2 + nCO
$nCO_2 = mCO_2/44.01$g/mol ; nCO = mCO/28.01 g/mol
$mT = mCO_2 + mCO$; $mCO = mT - mCO_2$
7.3009×10^{-3} mol = $\frac{mCO_2}{44.01} + \frac{0.2701-mCO_2}{28.01}$; mCO_2 = 0.1804 g.
nCO_2 = 0.1804 g/44.01 g/mol = 4.1001×10^{-3} mol. XCO_2 = 4.1001×10^{-3}/ 7.3009×10^{-3} = 0.5616

11 V = $\sqrt{\frac{2RT}{M}}$ if $V_{CO2} = V_{O2}$; then $\sqrt{\frac{2RTco_2}{MCO2}} = \sqrt{\frac{2RTO_2}{MO2}}$; $\frac{2RTO_2}{MO_2} = \frac{2RTco_2}{MCO2}$; $Tco_2 = TO_2(MCO_2/MO_2)$
TCO_2 = (44.01/32)(273.15K)= 375.6666 K = 102.5166 °C

12. Since ρ = PM/RT; M = RT(ρ/P).
From the table, the slope as ρ/P = 2.739 g-L^-/atm; M = (2.739)(0.08206)(20+273.15)
= 65.8891 g/mol.

13. Can't be predicted from the answer, since the choices are wrong. However, for 80% C, And 20% H, nC = 80/12.01 = 6.66111, nH = 20/1.01 = 19.8012 H/C = 3. For ~ 30 g/mol, formula of CH is C_2H_6.

14. t1 = 68.4 s. t2 = 83.8 s. M_1 = 28.02 g/mol
This is the application of Graham's Law of effusion. Assuming constant volume,

$$\frac{Rate\ 1}{Rate\ 2} = \sqrt{\frac{M_2}{M_1}} = \frac{t2}{t1} = \sqrt{\frac{M_2}{M_1}}$$

$\frac{83.8}{68.4} = \sqrt{\frac{M_2}{M_1}}$; M_2 = 42.0575 g/mol which is C_3H_6.

16. From Van der Waals equation:
a = $3(V_{mc}^2)P_C$ and b = $V_{mc}/3 = RT_c/8P_C$
Substitution yields to:
a = $(27/8)(bRT_C)$
$T_C = 8a/27bR$
$T_c = (8)(0.02138)/(27)(1.709 \times 10^{-5})(8.3145)$
T_C = 44.5816 K.

18. Using Poiseuille's Equation:

$$\mu = \frac{\pi P r^4 t}{8LV}$$

Pressure head for compressible liquid: $P = \frac{Pi^2 - Pf^2}{2P} = \frac{(1.1\ x 10^5\ )^2 - (1.090\ x\ 10^5)^2}{2x\ (0.95\ x\ 10^5)} = 1152.6316\ Pa$

$\mu = \frac{(3.14159)\ (1152.6316)(0.0005)^4(10)}{8(0.5)(0.0002)} = 2.8290\ x\ 10^{-6}\ Pa \cdot s$ or 2.8290 μPa-s

20. Linearize the equation by taking the natural logarithms of both sides.
lnμ becomes the ordinate, -1/T(K) becomes the abscissa.
Inputting the values and getting the y value at 25°C,
lnμ = $-(298.15)^{-1}\dot{y}$
lnμ = -0.065913
μ = 0.9362
This must be true since it must have a value midway 1.5 and 0.7.

22. r = 0.144 nm
MW = 107.87 g/mol

- FCCL
  n = 4
  a/r = $2\sqrt{2}$
  $\rho = \frac{nMW}{VN_A}$ where V = a^3

$$\rho = \frac{(4)(107.87)}{((0.144\ x\ 10^{-9})(2\sqrt{2}))^3(6.02214\ x\ 10^{23})(1000)} = 10604.42773\frac{kg}{m^3} = 10.6044\ g/mL$$

24. $\rho = 7.86\ g/cm^3$; MW = 55.85 g/mol

- BCCL
  n = 2
  a/r = $4/\sqrt{3}$

$\rho = \frac{nMW}{VN_A}$; $(7.86)(1000) = \frac{2(55.85)}{(1000)(6.02214\ x 10^{23})(V)}$
V= $2.3598 \times 10^{-29} = a^3$
a = 2.8683×10^{-10}
substitute to solve for r,
r = $2.8683 \times 10^{-10}/(4/\sqrt{3})$ = 1.2420×10^{-10} m or 1.2420 Å

26. m = 0.2m
Tfsol’n = -0.680°C; π = ? (at T = 0°C)
Π = iMRT
ΔT = Kfmi
0.680 °C = i(0.2m)(1.86 m/°C)
i = 1.8280
Assuming m = M
Π = (1.8280)(0.2 mol/L)(0.08206 atm-L/mol-K)(273.15 K)
Π = 8.1946 atm

28. Concentration = 0.72% wt HCl,
Tfsol’n = -0.706°C
MW of HCl =? (apparent)
v = 2. Assume that v ~ i
0.706 = m(2)(1.86)
m = 0.18978 mol/kg
for 100 g,
m = [0.72g/MW]/99.28g/1000g/kg
(0.18978) mol/g = $\frac{0.72\ g/MW}{\frac{99.28}{1000}kg}$
MW = 38.2128 g/mol

29. Apparent degree of dissociation:
M = 0.01 $Ke_3Fe(CN)_6$, Tsol’n = -0.062°C.
α = ?
Assuming that m = M
ΔT = Kfmi
0.062 = (1.86)(0.01)i
i = 3.333333
v = 4
α = $\frac{i-1}{v-1} = \frac{3.3333-1}{4-1} x\ 100\% =$ 77.7778%

34. ε = 0.16 V at T = 25°C
For Fe^{+2} when $[OH^-]$ = 0.10 M, $[Fe^{+3}]$ = 0.50 M and $[H_2O_2]$ = 0.35 M
Balancing the reaction: $\varepsilon° = \varepsilon_{cat} – \varepsilon_{anode}$
Since the reaction with hydroxide is more positive, it is the cathode. Iron reactions will be reversed, and multiplied to two. Since emf values are intrinsic, the values will remain the same.
$2Fe^{2+} \longleftrightarrow 2Fe^{+3} + 2e^-$ -0.77
$H_2O_2 + 2e^- \longleftrightarrow 2OH^-$ 0.88
ε° = 0.88 – 0.77 = 0.11 or ε° = ε°cat + ε°anode(reversed)
$\varepsilon = \varepsilon° - \frac{RT}{nF} lnK$; n =2 electrons
Where k is the equilibrium constant for the combined half-cell reactions:
$[H_2O_2] + 2[Fe^{+2}] \longleftrightarrow 2[OH^-] + 2[Fe^{+3}]$
k = $\frac{[Fe^{+3}]^2[OH^-]^2}{[Fe^{+2}]^2[H_2O_2]}$
$\varepsilon = \varepsilon° - \frac{RT}{nF} lnK$; 0.16V = 0.11V - $\frac{8.3145(25+273.15)}{2(96485.3399)} lnK$
k = 0.02040
Substitute k:
0.02040 = $\frac{[0.50]^2[0.10]^2}{[Fe^{+2}]^2[0.35]}$
$[Fe^{2+}]$ = 0.5917 M

35. t = 3.75 hrs; I = 2.83 A; T = 25°C; P_T = 742 mm Hg.
Finding the vapor pressure of H_2O from Perry:
$VP_{H2O} = e^{(73.649-\frac{7258.2}{T}-7.3037 lnT+4.1653\ x\ 10^{-6}T^2)}$ = 3170.3858 Pa
VP_{H2O} = 23.7798 mmHg
Using the formula:
$Q = It = \frac{mass}{MW} x \frac{no\ of\ electrons}{Xmol} xF$
Q = (3.75)(3600)(2.83) = 38205 C.
From the liberation: $SO_4^{-2} \xrightarrow{\qquad} SO_2 + O_2 + 2e^-$
n = 2 electrons
From the Partial pressures given, $XSO_2 = 1 - \frac{23.7798}{742} = 0.9680$
38205 C = $\frac{m}{MW} x \frac{2}{0.9680}$ X 96485.3399 C
And since m/MW = number of moles,
n_{moles} = 0.1916384
Substitute to the ideal gas equation: PV =nRT
V = (0.1916384)(0.08206)(25+273.15)/(742/760)
V = 4.8024 L

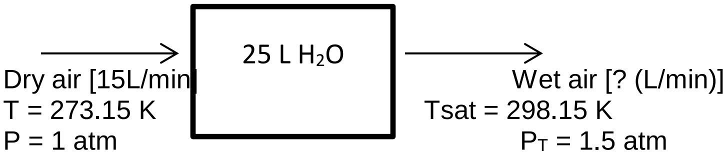
36. I = 0.555A; m = 1.32 g; MW = 197 g/mol
$Au(NO_3)_3 + H_2O \longleftrightarrow Au^{+3} + 3\ NO_3^{-1}$
$Au^{+3} + 3e^- \longleftrightarrow Au$
t = ?
q = It; t = q/I
q = $Fn_{Au}n$
n = 3 electrons; n_{Au} = 1.32/197 = 6.7005 x10^{-3}
t = $\frac{(96485.3399)(3)(6.7005\ x\ 10^{-3})}{0.555}$
t = 3494.5987 s = 58.2433 mins

38. Process: Distillation
$T_{mixture}$ = 95 °C; P_{solv} = 130 mmHg; P_{H2O}= 640 mmHg
Solvent is immiscible; MW_{Solv} = 150 g/mol; m_{H2O} = 200 kg
Using the fact that partial pressures can be used to find the mole fractions of the solution:
$X_{Solv} = \frac{130}{130+640} = 0.16883$
This is also the mole fraction which is: $\frac{m\ solv/MWsolv}{\frac{msolv}{MWsolv}+\frac{mH2O}{MW\ H2O}}$
$0.16883 = \frac{msolv/150}{\frac{msolv}{150}+\frac{200kg}{18.02}}$
m_{solv} = 338.1659 kg

40. At T_1 = -103°C, $P1_{CO2}$ = 76.7 mm Hg
At normal condition (P= 1 atm), T_2 = -78.5°C.
Heat of sublimation = ?
Using Clausius-Clapeyron equation:
$\ln|P_2/P_1| = \frac{\Delta Hsublimation}{R}(\frac{1}{T2} - \frac{1}{T1})$
Substitution:
$\Delta Hsublimation$ = 25777.4166 J/mol or 6160.9504 cal/mol

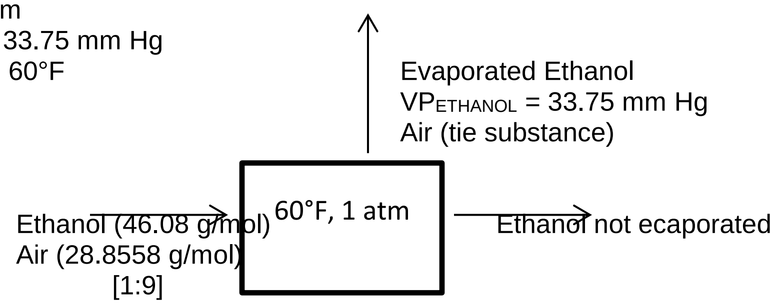
41.
V_{H2O} = 25 L
Rate of feeding (dry air) = 15 L/min at STP
Condition of saturated air with H_2O:

T = 25°C
P = 1.5 atm
t = ? (vaporize all H_2O)
At saturation:
P_{H2O} (Perry's 8th Ed.)= 3237.855 Pa
P_T = 1.5 atm = P_{H2O} + P_{air}
P_{air} = 1.4680 atm
Mass balance in air:



Wet air can be solved from Combined Gas Law:
$TsatPV_{dry} = P_{air}V_{wet}T_{STP}$
(1)(15L/min)(298.15) = (1.4680)(V_{wet})(273.15)
V_{wet} = 11.1528 L/min
Then the amount of water in saturation is: PV=nRT where the volume = V_{wet}
n = (0.031955)(11.1528 L/min)/[(0.08206)(298.15K)]
n = 0.0145666 mole/min H_2O
[Volume of leaving dry air = volume of H_2O removed]
To vaporize 25 L of H_2O, assume that the density is 1kg/L, n_{H2O} =1388.8889 moles
t = 1388.8889 moles/0.0145666 mole/min = 95347.4997 mins
t = 66.2135 days

42. Mass ratio: 9:1 (air:ethanol)
P_T = 1 atm
$P_{Ethanol}$ = 33.75 mm Hg
$T_{manifold}$ = 60°F



Finding the mole fraction of ethanol:

Xethanol = $\frac{\frac{1}{46.08}}{\frac{9}{28.8558}+\frac{1}{46.08}}$ = 0.060505

At final condition:

Xethanol = $\frac{33.75}{760} = 0.04441$

To find the amount of vapor from air mass balance:

Total mole of vapor = $\frac{9}{28.8558} \div (1 - 0.04441) = 0.32639$

Therefore, evaporated ethanol = 0.32639(0.04441) = 0.014495
From the feed that is 1/46.08 = 0.02170 mole of ethanol,
% evaporated = (0.014495/0.02170)100% = 66.7972 %

44. $PCl_{5(g)} \longrightarrow PCl_{3(g)} + Cl_{2(g)}$
T = 250°C, P = 1 atm
P = 4.4 g/L
Assuming that from the start of the reaction, no products are initially present and that the vessel is 1L,

$PV = nRT$
$n = (1)(1)/(250+273.15)(0.08206)$
$n = 0.023294$
Therefore, at all conditions, there is 0.023294 mole.
From the initial condition, mass = 4.4 g which is purely PCl_5.
$n_i = 4.4g/208.22\ g/mol = 0.02113$
$PCl_{5(g)} \longrightarrow PCl_{3(g)} + Cl_{2(g)}$
At equilibrium: $n_T = nPCl_5(1-\alpha) + \alpha(nPCl_5) + \alpha(nPCl_5) = nPCl_5(1+\alpha)$

$\alpha = n_T / nPCl_5 - 1$
$\alpha = 0.023294/0.02113 - 1$
$\alpha = 0.10233$

46. $CO_2 \longrightarrow O_2 + CO$
$T = 3000$ K, $P = 1$ atm, $\alpha = 0.40$
At $P = 2$ atm, $\%\alpha = ?$
For the equilibrium condition: $n_T = nCO_2(1+\alpha)$
Using the partial pressures: $P_T = P_{CO2}(1+\alpha)$; $1 = PCO_2(1+0.40)$
$P_{CO2} = 0.7143$ atm
$CO_2 \longrightarrow O_2 + CO$

Equilibrium: $PCO_2(1-\alpha)$ $PCO_2\ \alpha$ $PCO_2\ \alpha$
$$K_p = \frac{[O2][CO]}{[CO2]} = \frac{{PCO_2}^2\alpha^2}{PCO_2(1-\alpha)} = \frac{PCO_2\alpha^2}{(1-\alpha)} = \frac{0.7143(0.40)^2}{1-0.40} = 0.19048$$
From the expression $P_T = P_{CO2}(1+\alpha)$, Kp can be rewritten as:
$$Kp = \frac{PCO_2\alpha^2}{(1-\alpha)} = \frac{PT\alpha^2}{1-\alpha^2} = 0.19048$$
Substituting the new value for $P_T = 2$ atm,
$\alpha = 0.2949$

48. $K_{c1} = 1.90 \times 10^{-11}$ ($T_1 = 1227°C$)
$K_{c2} = 3.90 \times 10^{-19}$ ($T_2 = 727°C$)
Hrxn = ?
Using the equation of T-dependence:
$$\ln|K_2/K_1| = Hrxn/R\left(\frac{T2-T1}{T2T1}\right)$$
Substitution:
$$\ln|3.90 \times 10^{-19}/1.90\times10^{-11}| = (Hrxn/8.3145)\left(\frac{727-1227}{(727+273.15)(1227+273.15)}\right)$$
And since the process results to a decrease in entropy, the enthalpy becomes negative.
Hrxn = -441649.2052 J/mol = -441.6492 KJ/mol

50. Reaction: $O_{2(g)} \longleftrightarrow 2O_{(g)}$
$\ln K_p = -27.55$ at $T = 900$ K
$\Delta H = 67850 + 1.85T - 0.321 \times 10^{-3}T^2$ (cal/mole)
$\alpha = ?$ (at T= 4000 K and P = 1 atm)
Using the above equation:
$\ln|K_2/K_1| = Hrxn/R(\frac{T2-T1}{T2T1})$
$\ln|K_2| - \ln|K_1| = Hrxn/R(\frac{T2-T1}{T2T1})$
Using the given equation to solve for ΔH at 4000 K,: $1.85(4000) - 0.321 \times 10^{-3}(4000)^2 + 67850$
$\Delta H = 70114$ cal/mole
$\ln|K_2| + 27.55 = \frac{70114}{\frac{8.3145}{4.184}}(\frac{4000-900}{4000x900})$
$K_2 = 16.9831$
From the reaction, the expression is:
$K_2 = \frac{4\alpha^2 PO2^2}{PO2(1-\alpha)}$ where $P_T = PO_2(1+\alpha)$
Substitution:
$16.9831 = \frac{4\alpha^2 P_T}{(1-\alpha^2)} = \frac{4\alpha^2(1)}{(1-\alpha^2)}$

$\alpha = 0.89965$ or 89.9650%

II. Chemical Engineering Principles

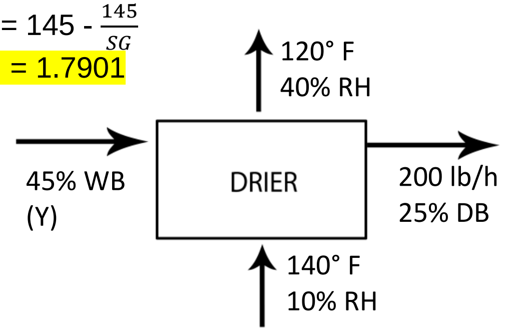
A. Chemical Engineering Calculations

2. S.G. = 0.82, reading = 85 mm
Since both pressures must be equal, P = ρgh
P = (1000)(0.82)(85/1000) = 69.7 Pa
69.7 Pa = (13.6)(1000)(h)/1000
h = 5.0876 mm

4. From the reading of a Baumė Scale of 64° Bė:
Since NaOH is heavier than water,
$°Bė = 145 - \frac{145}{SG}$
$64 = 145 - \frac{145}{SG}$
SG = 1.7901

$\dot{p}\ H_2O(120°\ F) = 87.55$ mmHg
$\dot{p}\ H_2O(140°\ F) = 149.44$ mmHg

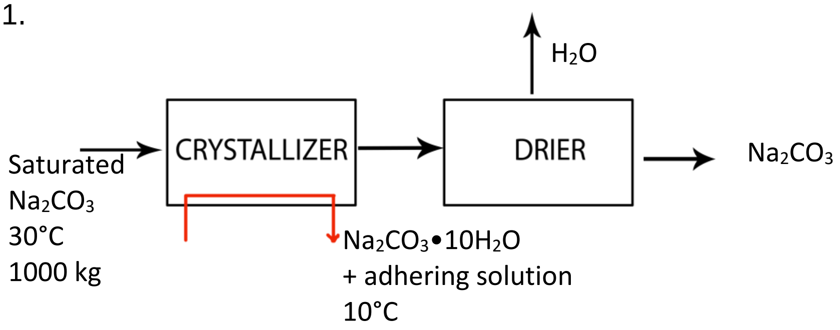
9.



Making a balance:
Let X = amount of water removed
Y(1-0.45) = 200[1-0.25(1+0.25)]
Y = 290.9091 lb/h
X = 290.9091 – 200 = 90.9091 lb/h

10. At 140° F, 10% RH:
$H_1 = \frac{149.44(0.10)(18)}{760-149.44(0.10)(29)} = 0.01245\ \frac{lb\ water}{lb\ d.a.}$
$H_2 = \frac{87.55(0.40)(18)}{760-87.55(0.40)(29)} = 0.02998\ \frac{lb\ water}{lb\ d.a.}$
X = A(H_2 – H_1)
A = 90.9091/(0.02998 – 0.01245) =5185.9156 lb d.a.
For the inlet humid volume,
$vH = \frac{359(459.67+140)}{459.67+32}\left[\frac{1}{29.87}+\frac{0.01248}{18.02}\right] = 14.9620\ ft^3/lb$
Volume of air = 14.9620(5185.9156) = 77 591.6688 ft^3/h

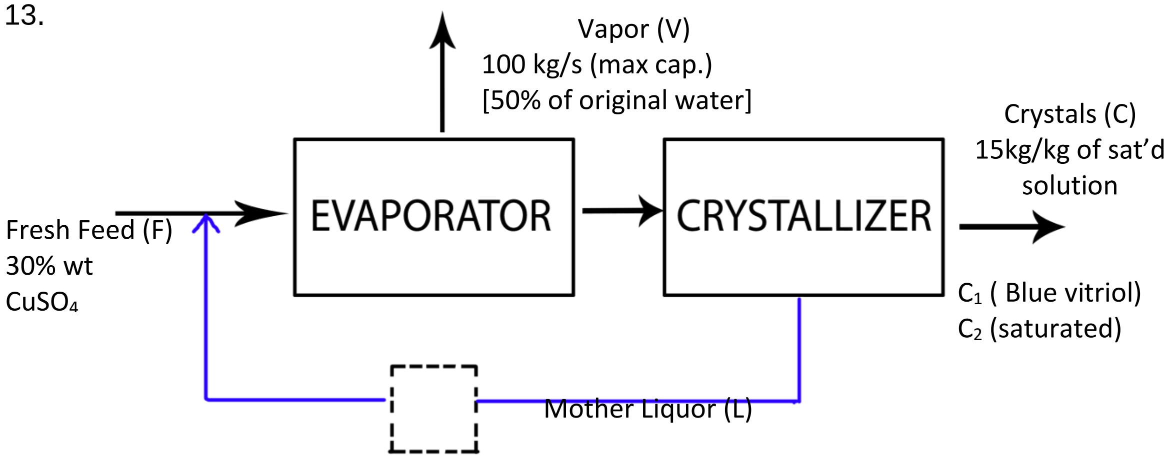
11.



Let
F = Feed;
L = Mother Liquor;
C = Crystals
xf = 38.8/(100+38.8) = 0.2795 {Fraction of dissolved crystals at 30°C, taken from the table given.}
xL = 12.5/(100+12.5) = 0.1111 {Fraction of dissolved crystals at 10°C, taken from the table given.}
xc = 105.99/286.19 = 0.3703 {Fraction of the anhydrous compound to the hydrated one.}
Balances:
OMB: F = L + C ; 1000 = L + C [1]
Crystal Balance: Fxf = LxL + Cxc; 1000(0.2795) = L(0.1111) + C(0.3703) [2]
Equating [1] and [2]:
L = 350.1736 kg
C = 649.8264 kg
With 5% of the L adhering to the crop,
0.05L = 17.5087 kg
Total anhydrous sodium carbonate comes from the adhered mother liquor and the crop (C) itself.
17.5087(0.1111) + 649.8264(0.3703)
Total = 242.6075 kg Na_2CO_3

12. If C = 500 kg, where same condition applies, except that no adhering solution accompanies the process, then the required variable is the new solubility of the mother liquor because it is dependent on the temperature.
L = 1000 – 500 = 500 kg
1000(0.2795) = 500(xL) + 500(0.3703)
xL = 0.1887
0.1887 = $\frac{x}{100+x}$; x = 23.2590 g
Interpolating this value setting x as the solubility and y as the temperature:
T = 21.0167 °C

13.



$CuSO_4•5H_2O$ = 249.55 g/mol
$CuSO_4$ = 159.55 g/mol
0.1251

xc = 0.6394
xL = 14.3/(14.3+100) =

xf = 0.30

Recycle stream is represented by the blue line.
OMB:
F = V + C; where V is at maximum capacity and C is broken down to C_1 and C_2. C_1 is the Blue vitriol component with the fraction xc, while the saturated component C_2, has a fraction of xL.
F = 100 + C_1 + C_2; since 15C_2 = C_1,
F = 100 + C_2 + 15C_2
F = 100 + 16C_2 [1]
Crystal Over-all balance:
Fxf = C_2xL + 15C_2xc
F(0.30) = C_2(0.1251) + 15C_2(0.6394)
F(0.30) = 9.7161C_2 [2]
Equating [1] and [2]:
F = 197.6528 kg
C_2 = 6.1033 kg
At the evaporator:
The fresh feed has 0.70F amount of water, which is 138.3570 kg
100 = 0.50(138.3570) + 0.50(H_2O in L)
H_2O in L = 61.643 kg
With the knowledge that xL = 0.1251,
0.1251 = $\frac{X}{X+61.43}; x = 8.7837$
L = x + H_2O in L = 8.7837 + 61.643 = 70.4267 kg
Ratio: F/L = 197.6528/70.4267
Ratio = 2.8065

14. Let Y_c = the crystals leaving the evaporator (kg) and Y_l = water accompanied in the crystals
Crystal Balance at the Evaporator:
197.6528(0.30) + 8.7837 = Y_c
Y_c = 68.07954 kg
Water Balance at the Evaporator:
61.643 + 138.3570 = 100 + Y_l
Y_l = 100 kg
% Composition = $\frac{68.07954}{68.07954+100} x100$
% Composition = 40.5044%

15. If wet crystals are dried, the crystals will all come from the C_1 and C_2. Since C_1 is a pure blue vitriol crystals, only C_2 will have its water removed. Therefore:
C_2 = (6.1033 kg)(0.1251) = 0.7635 kg
C_1 = 15(6.1033 kg) = 91.5495 kg
Total dried crystals = 92.313 kg

18. Given the reaction, using stoichiometry:
Basis: 100 moles of effluent
The C_2H_4 unconverted is 39.12 moles
Total C_2H_4 converted = C_2H_5OH + 2$(C_2H_5)_2O$ = 2.95 + 2(0.27)
Total C_2H_4 converted = 3.49 moles
Conversion = $\frac{3.49}{3.49+39.12}$
Conversion = 0.0819

19. Fractional yield of ethanol is the moles of converted ethanol/reactant consumed and unconsumed. This includes the ones converted to ethanol, unreacted ethylene and consumed ethanol that is converted directly to $(C_2H_5)_2O$.

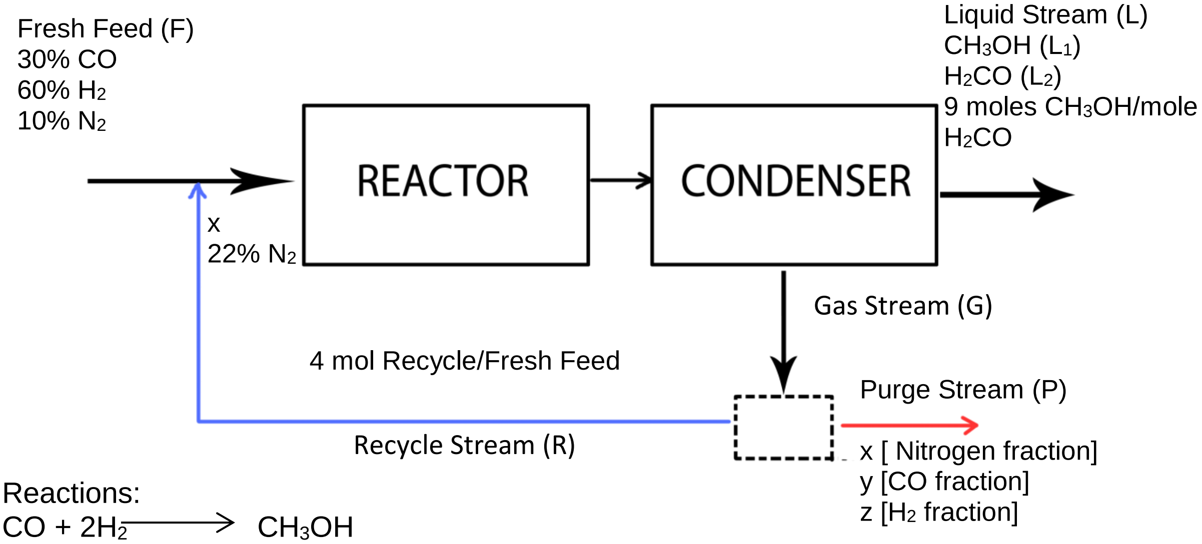
F. Yield $= \frac{2.95}{39.12+2.95+0.54}$

F. Yield = 0.06923

20. The presence of ethylene and ethanol in the effluent means that the two compounds were not used up, thus making up the excess reactants. The availability of water gives the theoretical amount of the products that can be produced.

$N_{THEO} = 45.08 - 0.27 + 2.95 = 47.76$
Excess = 39.12 + 2.95 = 42.07
Excess/Theo = 42.07/47.76
%Conversion (max) = 88.0863%

22.



Reactions:
$CO + 2H_2 \longrightarrow CH_3OH$
$CO + H_2 \longrightarrow H_2CO$

Note:
In a purge-recycle process, the components and mole fractions of P and R are the same, but not necessarily P = R.

Basis: F = 100 moles
R = 4F = 400 moles
Mixing Point Balance:
F + R = X
100 + 400 = X
X = 500 moles

N_2 Balance at the M.P.:
100(0.10) + 400(xN_2 of R) = 500(0.22)
xN_2 of R = 0.25
Thus, the Recycle and Purge streams have 0.25 mole fraction of Nitrogen gas.

Over-all Nitrogen Balance:
$100(0.10) = P(xN_2)$
$P = 10/0.25$
P = 40 moles

Over-all Carbon Balance:
Fresh feed Carbon $= L_1 + L_2 + Py$; where $L_1 = 9L_2$
$100(0.30) = 9L_2 + L_2 + Py$
$30 = 10L_2 + Py$ [1]

Over-all Hydrogen Balance:
Fresh feed H $=4 L_1 + 2L_2 + 2Pz$; where $L_1 = 9L_2$
$(100)(0.60)(2) = 36L_2 + 2L_2 + 2Pz$
$120 = 38L_2 + 2Pz$ [2]

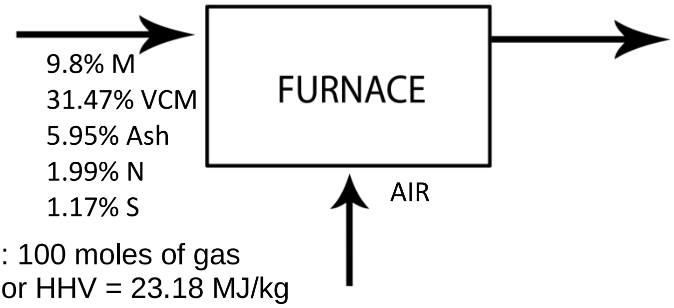
Equating [1] and [2], where P = 40 moles:
$80z – 152y = 6$ [3]
Since the mole fraction of N_2 in P is 0.25,
$x + y + z = 1$; $y + z = 1-0.25 = 0.75$
$y + z = 0.75$ [4]
Equating [3] and [4]:
y = 0.2328 (mole fraction of CO)
z = 0.5172 (mole fraction of H_2)

23. Single Pass Conversion is the ratio of the converted reactant to the product all over the total reactant i.e. from the Recycle and the Fresh Feed.

From the previous data, $L_2 = [30-40(0.2328)]/10 = 2.0688$ moles
$L_1 = 9L_2 = 9(2.0688) = 18.6192$ moles
S.P.C. $= \frac{L_1}{CO\ from\ P + CO\ from\ F} = \frac{18.6192}{30+0.2328(400)}$
S.P.C. = 0.1512
Note: If the formula in MRII will be used, the S.P.C = 0.1680 since L_2 is incorporated.

24. Over-all Conversion is the amount of converted reactant over the fresh feed.
O.A.C. $= \frac{L_1}{100} = \frac{18.6192}{30}$
O.A.C. = 0.6206
Note: If the formula in MRII will be used, the O.A.C. = 0.6896 since L_2 is incorporated.

29.



Basis: 100 moles of gas
GCV or HHV = 23.18 MJ/kg
FC = 100 – 9.8 – 31.47 -5.95
FC = 52.78

By Calderwood Equation:

$C = 5.88 + 2.206(GCV-0.094S) + 0.0053[80-100VCM/FC]^{1.55}$

$C = 5.88 + 2.206[23.18-0.094(1.17)] + 0.0053[80-100(31.47)/52.78]^{1.55}$

C = 57.3392 moles

30. CV of the VCM

$$CV_{VCM} = \frac{GCV(100)-CVCarbon(FC)}{VCM}$$

$$CV_{VCM} = \frac{23.18(100)-33.8(52.78)}{31.47}$$

CV_{VCM} = 16.9697 MJ/kg

31. % Volatile Carbon

Cvolatile = TC -FC

Cvolatile = 57.3392 – 52.78

Cvolatile = 4.5592

$$\%Voltile\ C = \frac{CVolatile}{VCM} x100\% = \frac{4.5592}{31.47} x100\%$$

%Volatile C = 14.4875%

Note: The answer given by the book is 67.33% which is the combined water in the VCM that is not the answer to the question asked.

CW = 100 – M – N –S –Ash –NH - TC

Using Dulong's Formula:

23.18 = 0.338(57.3392) + 0.094(1.17) + 1.44(NH)

NH = 2.5621

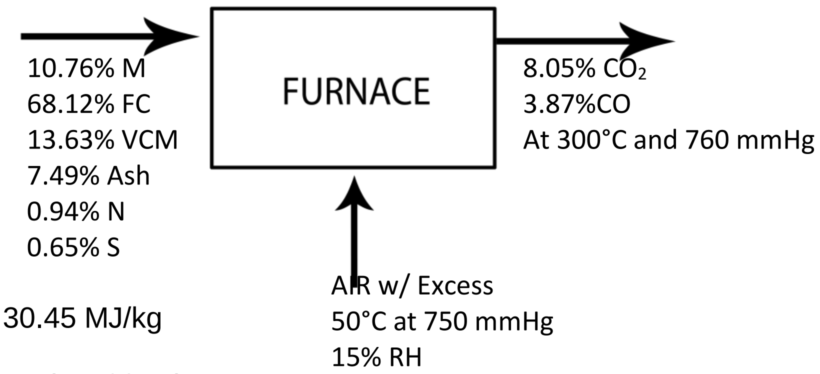
CW = 100 - 9.8 – 1.99 – 1.17 -5.95 – 2.5621 – 57.3392

CW = 21.1887

%CW=CW(100%)/VCM = 21.1887/31.47

%CW = 67.3300%

33.



GCV = 30.45 MJ/kg

Basis: 100 kg of feed

Using Calderwood Equation:

$TC = 5.88 + 2.206[30.45 – 0.094(0.65)] + 0.0053[80-100(13.63)/68.12]^{1.55}$

TC = 75.9400 kg

Using Dulong's Formula:

30.45 = 0.338(75.9400) + 1.44(NH) + 0.094(0.65)

NH = 3.2786 kg

Theo O_2 = at C + NH/4 = 75.94/12 + 3.2786/4
Theo O_2 = 7.1480 kmoles

DSG Balance:
75.94/12 = DSG(0.0805+ 0.0387)
DSG = 53.0900 kmoles
DSG = CO + CO_2 + N_2 + Free O_2; Free O_2 = Excess O_2 + CO/2 + H_2/2 and N_2 = 79(O_2 air)/21
Where O_2 in air = Excess O_2 + Theo O_2
DSG = CO + CO_2 + EO_2 + CO/2 + (EO_2 + TheoO_2)79/21
53.09 = 4.2738 + 2.0546 + EO_2 + 2.0546/2 + (EO_2 + 7.1480)(79/21)
EO_2 = 3.9573 kmoles

%Excess = EO_2(100%)/TheoO_2 = 3.9573(100%)/7.148
%Excess Air = 55.3627%

34. Volume of wet air water will come from the humid air.
At $\dot{p}$ = 92.53 mm Hg, 15% RH
H = $\frac{92.53(0.15)}{750-92.53(0.15)} x \frac{3.9573+7.1480}{0.21} = 0.9971\ kmoles$
Wet air (WA) = (3.9573 + 7.148)/0.21 + 0.9971 = 53.8794 kmoles
vWA = (53.8794/100)(22.414)(760/750)[(273.15+50)/273.15]
vWA = 14.4776 m^3/kg
vWA/100 g coal = 14.4476(1000)/100
vWA/100 g coal = 1.4478 m^3/g

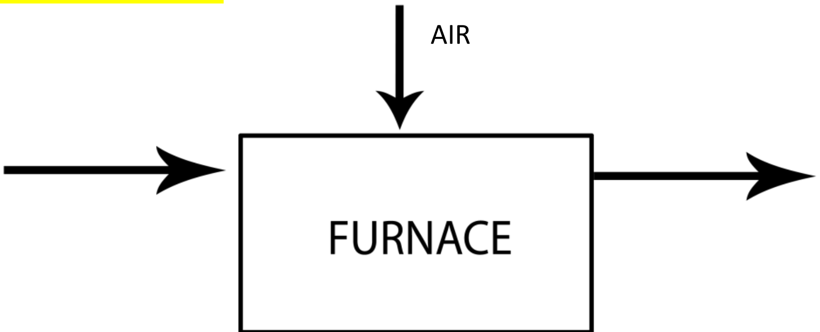
35. H_{Vap} = 44.01 kJ/mol at T = 25°C.
CW = 100 – 75.94 – 0.94 – 0.65 – 10.76 – 7.49 – 3.2786 = 0.9414 kg
Total H = CW(2/18) + M(2/18) + NH
Total H = (0.9414 + 10.76)(2/18) + 3.2786 = 4.5786 kg or kmole
CV lost due to H_2O uncondensed = $\frac{Total\frac{H}{2}+(Water\ in\ Humid\ Air)(Hvap)}{GCV} = \frac{\frac{4.5786}{2}+0.9971(44.01)}{30.45}$
CV lost due to H_2O uncondensed = 4.7500

36. Check the VCM/FC relationship for HV bituminous coal and the refuse.
VCM/FC_{Coal} = 0.1532; VCM/FC_{Refuse} = 0.37622 [not equal!]

This is the mixture of coked and uncoked coal since VCM_{Refuse} is greater than 0.2%.

Wt of VCM_{refuse} = (2.8)(0.046)/0.841 = 0.1532
Wt of FC_{refuse} = 2.8(0.113)/0.841 = 0.3762
CV_{VCM} = $\frac{34.75(100)-64(33.8)}{25.6} = 51.2422\ MJ/kg$
CV_{Lost} = 33.8(0.3762) + 51.2422(0.1532) = 20.5659
%CVlost = 20.5659(100%)/(100)34.75
%CVlost = 0.5918%

37.



COAL
19.04% VCM
8.18% Ash
80.31% C
0.87% N
0.71% S

STACK GAS
13.35% CO_2
1.85% CO

REFUSE
4.12% VCM
63.14% Ash
32.74% FC

5.5% of the Carbon fired to the furnace is lost in the refuse.

Basis: 100 kg coal
Ash Balance:
100(0.0818) = R(0.6314)
R = 12.9553 kg
Wt of C in the Refuse = 0.055(80.31) = 4.41705 kg
Wt of C in the VCM = 4.41705 – 0.3274(12.9553) = 0.17548 kg
% C in the VCM = 0.17548(100)/[(0.0412)(12.9553)] = 32.8763%
% FC = 80.31 – 0.328763(19.04)
% FC = 74.0504%

Using the Calderwood Equation:
$80.31 = 5.88 + 2.206[GCV - 0.094(0.71)] + 0.0053[80-100(19.04)/74.0504]^{1.55}$
GCV = 32.6331 MJ/kg

38. Using Dulong's Formula:
32.6331 = 0.338(80.31) + 1.44NH + 0.094(0.71)
NH = 3.7650 kg
Theo O_2 = 80.31/12 + 3.7650/4 = 7.6338

C gasified: 80.31(1-0.055)/12 = 6.3244 kmoles
Total C Balance:
6.3244 = DSG(0.1335 + 0.0185)
DSG = 41.6079 kmoles

DSG Balance:
CO_2 + CO + CO/2 + EO_2 + VCMlost(NH)/4 + C in the refuse +(EO_2 + Theo O_2)79/21 + N/2

41.6079 = 5.5547 + 0.7698 + 0.7698/2 + EO_2 + [0.0412(12.9553)(3.7650)]/[4(0.1904)(100)] + 0.055(80.31)/12 + (EO_2 + 7.6338)79/21 + 0.87/28
41.6079 = 7.3725 + EO_2 + (EO_2 + 7.6338)(79/21)
EO_2 = 1.1587 kmoles

%Excess air = 1.1587(100%)/7.6338 = 15.1790%

41. Basis: 100 mole of SG
O_2 in air = 83.02(21)/79 = 22.0686
O_2 for SO_3 = 22.0686 – 4.93 – 12.05 = 5.0866

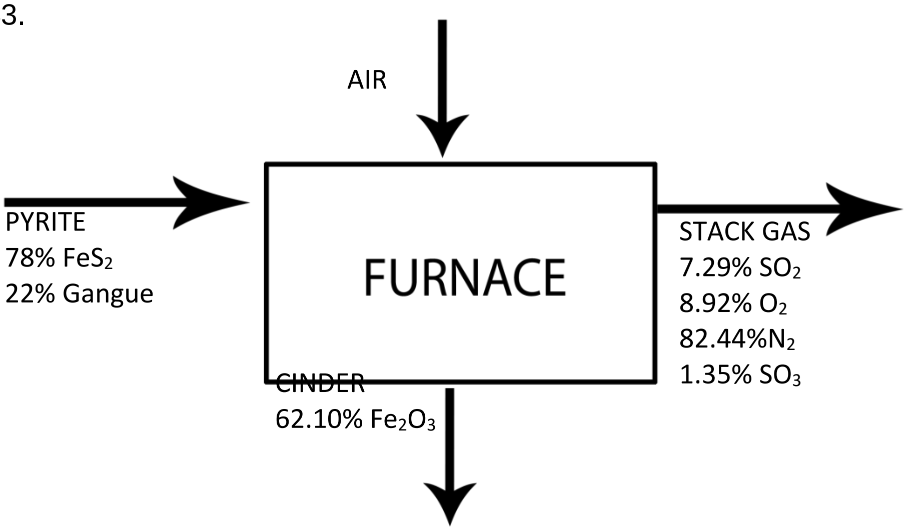
Using this O_2 for computing excess oxygen,
% Excess = (22.0686-5.0866)(100%)/5.0866
% Excess = 333.8576%

However, if the method in Stoichiometry will be used, the value of the % Excess will be negative. This method is done by finding the total S converted to SO_3 (23.1636).

42. The cinder will be composed of the inerts and the unburned sulfur.
$S + O_2 \longrightarrow SO_2$; $S + 1.5O_2 \longrightarrow SO_3$

Wt of inert = 1150(0.10)/0.90 = 127.7778 g
From the SG analysis, the converted S is 3.3924(32.06) = 108.7603 g
xS in the cinder = 108.7603/(108.7603+127.7778) = 0.4598

43.



Basis: 100 moles of Stack Gas

Reactions:
$4FeS_2 + 11O_2 \longrightarrow 2Fe_2O_3 + 8SO_2$
$4FeS_2 + 15O_2 \longrightarrow 2Fe_2O_3 + 8SO_3$
O_2 from air = 82.44(21)/79 = 21.9144 moles
O_2 for SO_3 = 21.9144 – 8.92 – 7.29(11/8) = 2.97065 moles
Thus SO_3 in the cinder = 2.97065(8/15) – 1.35 = 0.2343 moles
Wt of SO_3 in the cinder = 0.2343(80.06) = 18.7618 g

Using the stoichiometric relations to find the FeS_2 in the Cinder,
FeS_2 in the cinder = 0.2343(4/8) = 0.11715 moles
Wt of FeS_2 in the Cinder = 0.11715(119.77) = 14.0311 g

To find the amount of feed:
Total Fe_2O_3 = 7.29(2/8) + 1.5843(2/8) = 2.2186 moles
Wt of Fe_2O_3 in the cinder = 2.2186(159.3) = 353.4190 g
Total weight of Cinder: 353.4190/0.6210 = 569.1127 g

FeS_2 balance:
Pyrite(0.78) = (4/8)(1.35 + 7.29)(119.77) + 14.0311 + unburned FeS_2

Pyrite(0.78) = 531.4375 g + unburned FeS_2 [1]

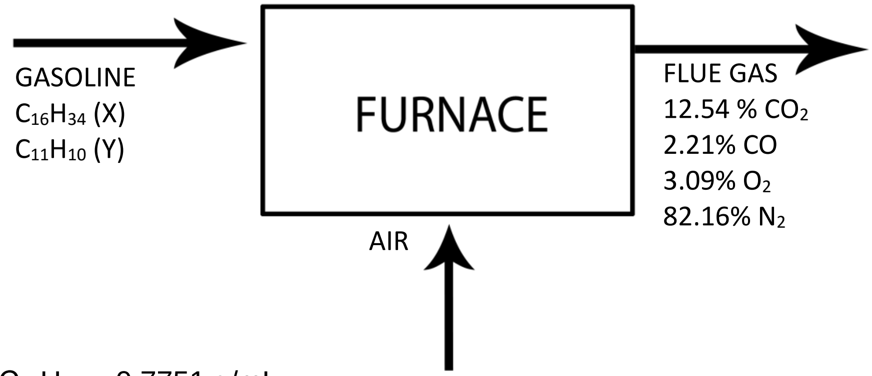
Gangue Balance:
Cinder = SO_3 + gangue + Fe_2O_3 + unburned FeS_2
Gangue = 569.1127 – 18.7618 – 353.4190 – unburned FeS_2
Pyrite(0.22) = 196.9319 – unburned FeS_2 [2]

Equating [1] and [2]:
Pyrite = 728.3694 g
Unburned FeS_2 = 36.6906 g

FeS_2 in the Pyrite = 728.3694(0.78) = 568.1281 g
FeS_2 lost in the Cinder = FeS_2 (cinder)/ FeS_2 (pyrite) = 36.6906(100)/568.1281
FeS_2 lost = 6.4582%

45. An n% oleum means it contains (100-n)% H_2SO_4 and n% of SO_3.
A 40% oleum therefore, contains (100-40)% oleum which is 60%.

46.



ρ of $C_{16}H_{34}$ = 0.7751 g/mL
ρ of $C_{11}H_{10}$ =1.025 g/mL
Note: Cetane number is the volume% of cetane in a cetane mixture.
Basis: 100 moles of flue gas
Total C: 12.54 + 2.21 = 14.75 moles
O_2 from air = 82.16(21/79) = 21.84 moles
O_2 unaccounted for = 21.84 – 3.09 – 12.54 – 2.21/2 = 5.105 moles
Total H = 5.105(4) = 20.42

Total C balance:
16X + 11Y = 14.75 [1]
Total H balance:
34X + 10Y = 20.42 [2]
Equating [1] and [2],
X = 0.3604 moles
Y = 0.8167 moles
Finding the volumes of X and Y:
VX = (0.3604 mol)(226.5 g/mol)/(0.7751 g/mL) = 105.3162 mL
VY = (0.8167 mol)(142.21 g/mol)/(1.025 g/mL) = 113.3102 mL
Cetane Number = VX(100)/(VX +VY) = 105.3162(100)/(105.3162+113.3102)
Cetane Number = 48.1718

49. $\Delta H = -2658$ kJ/mol

$2C_4H_{10} + 13O_2 \longrightarrow 8CO_2 + 10H_2O$

Basis: 2 moles of butane

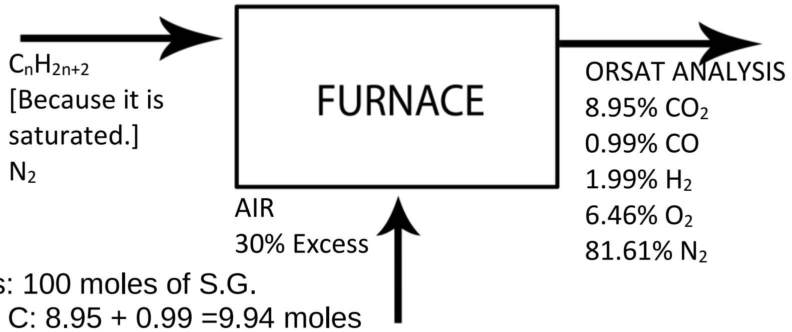
HHV or GCV = NCV + $\frac{moles\ of\ H2O\ from\ Combustion}{Total\ Moles\ of\ Fuel} x\ Lc\ of\ Water$

Since Lc of Water = 44.04 MJ/kmol and NCV = $-\Delta H$combustion

GCV or HHV = -(-2658kJ/mol) + $\frac{10}{2}$(44.04)

GCV = 2878.2 MJ/kmol or kJ/mol

50.



Basis: 100 moles of S.G.

Total C: 8.95 + 0.99 =9.94 moles

Excess O_2 = Free O_2 – CO/2 – H_2/2 = 6.46 – 0.99/2 – 1.99/2 =4.97 moles

%Excess = $\frac{Excess}{O2\ air - Excess}$; 0.30 = $\frac{4.97}{O2\ in\ air - 4.97}$; O_2 in air = 21.5367 moles

O_2 unaccounted = 21.5367 - 0.99/2 – 6.46 – 8.95 = 5.6317 moles

Total H = 5.6317(4) + 1.99(2) = 26.5068 moles

$\frac{at\ C}{at\ H} = \frac{X}{2X+2} = \frac{9.94}{26.5068}$; X = 3.000

Therefore the gas is C_3H_8.

B. Chemical Engineering Thermodynamics

5. Joule-Thomson effect is the change in temperature if it is forced in an isenthalpic process.

Its coefficient is defined as the negative enthalpy change over the pressure change at an isothermal process, divided by the specific heat.

$\mu = -\left(\frac{\partial H}{\partial P}\right)_T \left(\frac{1}{Cp}\right)$

Using P values as the abscissa and H values as the ordinate, the slope = $\left(\frac{\partial H}{\partial P}\right)_T$ = 19.9107

$\mu = 19.9107(1/0.6923)$

$\mu = 28.7602$ K-MPa^{-1}

8. The heat of combustion is the energy released as heat when a compound undergoes complete combustion with oxygen under standard conditions (Wikipedia, 2015).

m = 400 mg
$\Delta T = 2.86°C$
$Cp_{cal} = 4.15$ kJ/K
MW of ethanol = 46.08 g/mol
ΔH comb = $Cp_{cal}\Delta T/n$
ΔH comb = (4.15 kJ/K)(2.86K)/[(0.4/46.08)]
ΔH comb = -1367.3088 kJ/mol

10. For van der waals gas, in a reversible expansion:

$\Delta U = nCv\Delta T + n^2 a\left(\frac{1}{Vi} - \frac{1}{Vf}\right)$
$\Delta U = 2(28)(100-250) + 2^2(0.1408)(1000/5 - 1000/80)$
$\Delta U = -8294.4$ J or -8.2944 kJ

11. For an adiabatic expansion,

$(V-b)^R(T)^{Cv}$ = constant (k)
$(5/1000 - 3.913 \times 10^{-5})^{8.3145}(250)^{28} = k$
$k = 9.5948 \times 10^{47}$
$k = (V/1000 - 3.913 \times 10^{-5})^{8.3145}(100)^{28}$
V = 108.5914 L

13. The condition is against an external pressure. Work in this case is the differential volume multiplied to whatever the external pressure is.

$V_1 = 0.6$ L
$V_2 = 1.2$ L
T = 0°C
$P_{ext} = 0.9$ atm
$W = -P_{ext}dV$
$W = -0.9(101325)(1.2 - 0.6)/1000$
W = 54.7155 J

14. The condition is against a variable pressure: $PV^n = k$

To solve for n, we first use the two values given on the table and determine if the n value will fit to all given data.

$PV^n = k$
$0.194(0.6/1000)^n = 0.134(0.8/1000)^n$

n = 1.2862

This value will give a constant of 1.38 x 10^{-5} to 1.39 x 10^{-5} values which do not significantly differ from each other. Thus, n can be concluded to be correct.

Because there is no specific volume to which we could probably evaluate the term, we will use the average volume to provide a possible constant pressure.

Vav = (Vi + Vf)/2 = (0.6 + 1.2)/2 = 0.9 L

$P(0.9)^{1.2862} = 0.194(0.6)^{1.2862}$

P = 0.1152 atm

Therefore, the work is W = PdV

W = 0.1152(101325)(1.2-0.6)/1000

W = 7.0013 J

Why not use linearization? Linearization will provide the slope of the linearized value for natural logarithms. However, this does not conform to the relationship as $PV^n = k$, because in the first place, you do not know if the plot of the graph will really likely be linear.

15. If the gas is assumed ideal for an isothermal, reversible expansion:

T = 273.15 K

Vi = 0.6 L; Vf = 1.2 L

n = 0.1 mole

W = nRTln|Vf/Vi|

W = 0.1(8.3145)(273.15)ln|1.2/0.6|

W = 157.4210 J

16. Assuming a van der Waals gas:

a = 0.86 Pa-m^6/mol^2

b = 3.18 x 10^{-5} m^3/mol

$$W = nRT\ln\frac{Vf-nb}{Vi-nb} + n^2a\left(\frac{1}{Vf} - \frac{1}{Vi}\right)$$

$$W = 0.1(83145)(273.15)\ln\frac{1.2/1000-0.1(3.18\ x\ 10^{-5})}{0.6/1000-0.1(3.18\ x\ 10^{-5})} + 0.1^2(0.86)\left(\frac{1000}{1.2} - \frac{1000}{0.6}\right)$$

W = 150.8586 J

18. The process is an adiabatic, reversible expansion of an ideal gas.

m = 20g of Oxygen gas

T_1 = 25° C

P_1 = 0.1 atm

P_2 = 3 atm

Using these values, final temperature can directly be calculated as:

$T_1P_1^{(1-\gamma)/\gamma} = T_2P_2^{(1-\gamma)/\gamma}$

Substituting the values above and with the idea the oxygen gas is diatomic with γ = 1.4,

T_2 = 787.8970 K

Note: This answer differs from that of the manual. See explanation after number 19, next page.

19. For an adiabatic process, q = 0. Therefore, ΔU = W

W = nCvΔT where Cv = (5/2)R

W = 20/32(5/2)(8.3145)(787.8970-298.15)

W = 6362.5022 J

Note:

Answers in 18 and 19 differ, that is because, the given should've been $P_2 = 0.3$ atm.

For this given, the answer in no. 18 would've been: $T_2 = 408.0893$ K which is still a lot different from the choices. This makes the choices wrong since ideally, if the pressure is increased, the final temperature shall increase too.

Then for the work, using the same formula: W = 1428.2656 J, which is the correct answer given by the manual at the back.

21. at STP, T = 273.15 K
$PV = nRT$
$\alpha = 1/T = nR/PV = 1/273.15\text{K} = 1(8.3145)(1000)/[101325(22.414)]$
$\alpha = 3.6610 \times 10^{-3}/\text{K}$

22. The over-all mechanical energy balance:
$\Delta H + \Delta KE + \Delta PE = Q - W_s$
$H_2 - H_1 + \frac{1}{2}(v_2{}^2 - v_1{}^2) + z_2 - z_1 = Q - W_s$

The process does not involve shaft work, thus Ws = 0. On the assumption that the nozzle is not elevated, $z_2 - z_1 = 0$.
Thus the equation is reduced to:
$H_2 - H_1 + \frac{1}{2}(v_2{}^2 - v_1{}^2) = Q$
From the given, Heat loss = 10 kJ/s, m = 0.5 kg/s
Thus $Q = -m^{-1}$Heat loss $= -(0.5 \text{ kg/s})^{-1}(10 \text{ kJ/s})$
$Q = -20$ kJ/kg

To find v_1: Q/A_1 where Q = (specific volume)(mass flow rate)/Area
$v_1 = \frac{(0.5\text{ kg/s})(0.12547\text{ m3/kg})}{\frac{\pi}{4}(0.05^2)} = 31.9507\ m/s$
$H_1 = 3023.5$ kJ/kg (from the table)
$H_2 = 2803.3$ kJ/kg (from the table)
Substituting all these values to the equation to find v_2,
$(2803.3 - 3023.5)1000 + ½(v_2{}^2 - 31.9507^2) = -20(1000)$
Note: The factor 1000 is the conversion of kJ to Joules.
$v_2 = 634.38292$ m/s

$v_2 = (\text{sp.volume})(m)/A_2$
$A_2 = 0.14302(0.5)/634.3829$ [Some values were taken from the given table.]
$A_2 = 1.1272 \times 10^{-4}\ \text{m}^2 = \pi d^2/4$
$d_2 = 1.1980$ cm

24. Because the collector works at 190°F, where it rejects heat at the atmospheric temperature, we have to assume that this collector works as a Carnot engine to devise the relationship between the high and low temperatures.

Q loss = Q gain

During the transfer of the collected energy, it is accompanied by the losses because of temperature differences and thus efficiency is incorporated.

$\eta QA = -W_s$ where the efficiency $\eta = 1 - T_c/T_h$
$(1 - \frac{70+459.67}{190+459.67})(200 \text{ BTU/h-ft}^2)(A) = -(1000 \text{ W})(\frac{1\ BTU/h}{0.29307\ W})$
$A = 92.3656\ \text{ft}^2$

26. The minimum work for this process is the work accompanied by the freezing of water into ice incorporating the coefficient of performance.

Tc = 32°F
Th = 85°F
H_{fusion} = 143 BTU/lb
m = 10 lbs
$-mH_{fusion}$ = -Work(c.o.p.) where c.o.p. = Tc/(Th-Tc)

Work = $\left(\frac{32+459.67}{85-32}\right)^{-1}(10\ lbs)(143\frac{BTU}{lb})$

Work = 154.1481 BTU

27. T_1 = 70 °F; T_2 = 30 °F; T_{atm} = 80 °F; Preq = 40 kW; V = 100 gal/min; ρ = 1.2 kg/L
Cp = 3.3 kJ/kg-K

Q = ηmCpΔT

Q = $(1-\frac{30+459.67}{80+459.67})\left(3.3\frac{kJ}{kg-K}\right)\left[(70-30)\left(\frac{5}{9}\right)+273.15\right](378.5412\ L/min)(1.2\frac{kg}{L})(\frac{1\ min}{60\ s})$

Q = 683.7045 kW

Since Q > Prequired, the refrigerator cannot be used.

29. The problem can be explained briefly into:

A. For the ice: Temperature of ice to 273.15 K, then fusion to water, and lastly water temperature to increase at a final temperature.

B. For the water: Temperature of water to drop into final temperature.

Because the ice absorbs heat and the water does the opposite, $Q_{loss} = Q_{gain}$

$Q_{gain} = m_{ice}Cp_{ice}\Delta T_1 + m_{ice}H_{fus} + m_{ice}Cp_{water}\Delta T_2$ [1]

$Q_{loss} = m_{water}Cp_{water}\Delta T_3$ [2]

ΔT_1 is the temperature gradient from the initial temperature of ice (T_{ice}) to its freezing point, T = 273.15 K.

ΔT_2 is the temperature gradient from freezing point to its final temperature (T_f).

ΔT_3 is the temperature gradient from the initial temperature of water (T_{water}) to the final temperature (T_f).

Assuming that all ice melts, T_f should be greater than 273.15 K.
Equating [1] and [2] and substituting the temperature gradients:
$m_{ice}Cp_{ice}(273.15 - T_{ice}) + m_{ice}H_{fus} + m_{ice}Cp_{water}(T_f - 273.15) = m_{water}Cp_{water}(T_{water} - 273.15)$
Substituting all values wher Cp_{ice} = 37.15 J/mol-K and Cp_{water} = 75.48 J/mol-K:
$(20/18.02)(37.15)(5) + (20/18.02)(6.008)(1000) + (20/18.02)(75.48)(T_f - 273.15) = (100/18.02)(75.48)(363.15 - T_f)$

T_f = 334.4736 K or 61.3236° C

The assumption is also correct that all ice melted. This should be the correct answer.

30. The entropy change is determined by the net change brought by the change in phase and the changes in temperatures for both ice and water.

$\Delta S_{total} = \Delta S_{ice} + \Delta S_{water}$
For this processes with temperature gradient, ΔS = nCpln|Tf/Ti| and $\Delta S = nH_{fus}/273.15$
ΔS_{total} = (20/18.02)(37.15)ln|273.15/268.15| + (20/18.02)(6.008)(1000)/273.15 + (20/18.02)(75.48)ln|334.4736/273.15| + (100/18.02)(75.48)ln|334.4736/363.15|

ΔS_{total} = 7.6858 J/K

32. The system is treated as an incompressible fluid, thus its volume does not change.
Note that $\Delta G = \Delta H - T\Delta S$ where $\Delta H = dH$. Applying the relationship $dU = dQ - pdV$
$dH = dQ + VdP$ [1] where $dQ = TdS$ [2]
Substituting [2] to [1] we get, $dH = TdS + VdP$
Thus, the final equation is: $\Delta G = TdS + VdP - T\Delta S$ where Δ means the change in which we can cancel out the expression TdS and TΔS since they are equal.
$\Delta G = VdP$
Assuming that ρ of water = 1000 kg/m^3:
$V = MW/\rho = (18.02 g/mol)(1/1000)/1000 = 1.802 \times 10^{-5}\ m^3/mol$
$\Delta G = 1.802 \times 10^{-5}\ m^3/mol(2-1) \times 10^5\ Pa$
$\Delta G = 1.802\ J/mol$

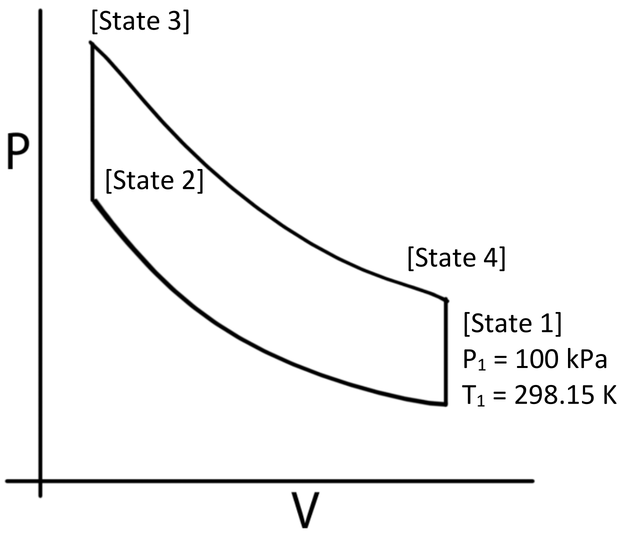
33. If a fluid enters a turbine, the process is isentropic and usually, if the steam is the feed, the entropy of the whole system is defined by the vapor entropy.
$S_1 = 7.1229$ (at 1 MPa)
$S_2 = 7.1229$ (t 0.7 MPa)
Interpolating between the values of the given, $T_2 = 254.3781°C$.
Here, $H_2 = 2962.9254\ kJ/kg$

Work = $-m\Delta H$
Work = $-(5kg/s)(2962.9254 - 3051.2) kJ/kg$
Work = 441.3732 kW

Note: Another solution using x (vapor fraction) for the enthalpy calculation using the fact that entropy is constant might draw attention. However, the problem says 'steam' which presumably, the phase was not affected during the decrease in pressure.

34. Isentropic efficiency is the ratio of the actual work to the isentropic work.
The isentropic work was calculated to be 441.3732 kW (no. 33).
To find the actual work, use $T_2 = 255°C$ as given:
Via interpolation: $H_2 = 2964.25\ kJ/kg$
Actual W = $-(3051.2-2964.25)(5) = 434.75$ kW
$\eta_{isentropic}$ = actual work(100%)/isentropic work = 434.75(100%)/441.3732
$\eta_{isentropic} = 98.4994\%$

36-37: Ideal Otto cycle



36. The thermal efficiency of an Otto cycle is the ratio of the W_{net} to Q_{in}.
$\eta = W_{net}/Q_{in} = 1 - r^{1-\gamma}$
where γ is the adiabatic constant and r is the compression ratio.
Air has $\gamma = 1.4$ and given that $r = V_1/V_2 = 10$,
$\eta = 1- (10)^{1-1-.4}$
$\eta = 0.6019$

Note: This problem can also be solved in a longer way, by using W_{net} and Q_{in}.

37. Mean effective pressure Is the ratio of the W_{net} to the difference of the maximum and minimum volume.
$MEP = W_{net}/(V_{max} - V_{min})$
To calculate W_{net}, obtain the differences between the works from 3 through 4 and 1 through 2.
Assume 1 mole of air.
$T_2 = T_1(r)^{\gamma-1} = 298.15(10)^{1.4-1}$
$T_2 = 748.9189$ K
From the given that 1000 kJ/kg was used to transfer heat at constant volume:
$U = mCv\Delta T$
$1000 = (5/2)(8.3145)(1/29)(T_3 - 748.9189)$
$T_3 = 2144.0720$ K
$T_4 = T_3(1/r)^{\gamma-1}= T_4 = 2144.0720(1/10)^{1.4-1}$
$T_4 = 853.5704$ K

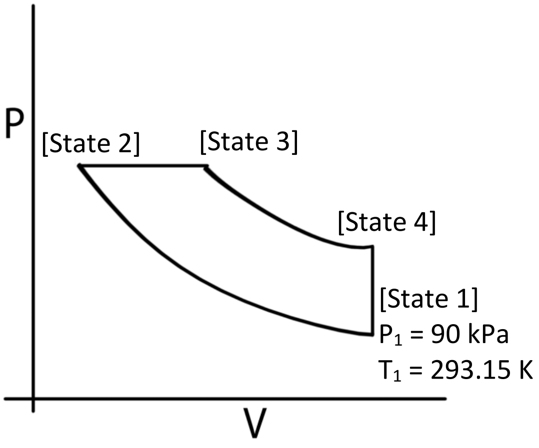
$W_{net} = \Delta U_{3-4} - \Delta U_{1-2}$
$W_{net} = Cv(T_3 - T_4) - Cv(T_2 - T_1)$
$W_{net} = [(5/2)(8.3145)][(2144.0720 - 853.5704) - (748.9189 - 298.15)]$
$W_{net} = 17454.8938$ kJ/mol

V_{max} = Volume at state 1
$V_{max} = 8.3145(298.15)/100x10^3 = 0.02479\ m^3$
$V_{min} = V_{max}/10 = 2.4790 \times 10^{-3}\ m^3$

$MEP = W_{net}/(V_{max} - V_{min}) = 17454.8938$ kJ/mol/$(0.02479 - 2.4790 \times 10^{-3})$
MEP = 782.3448 kPa

Note: W_{net} can also be calculated using the differences from states 2 through 3 and 1 through 4.

38-39. Ideal Diesel Cycle



For air, $\gamma = 1.4$ where $V_1/V_2 = r = 15$. Maximum temperature occurs when pressure is greatest and volume is largest. Therefore, that point is at state 3. Thus, $T_3 = 2000°C$.

38. The net work is the difference in the work brought by the changes from 2 to 3 and from 4 to 1.

Assuming 1 mole of air:
From the given data, using $PV = nRT$, $V_1 = 0.02708\ m^3 = V_{max}$
$T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$
$T_2 = 293.15(15)^{1.4-1}$
$T_2 = 866.01697\ K$
$V_2 = 0.02708/15 = 1.8055 \times 10^{-3}\ m^3 = V_{min}$
At constant pressure, Boyle's Law can be used to solve for V_3.
$V_3 = T_3V_2/T_2$
$V_3 = 2273.15(1.8055 \times 10^{-3})/866.01697$
$V_3 = 4.7392 \times 10^{-3}\ m^3$
Using the adiabatic relationship:
$T_4 = (V_3/V_4)^{\gamma-1}(T_3)$ where $V_4 = V_1$
$T_4 = (4.7392 \times 10^{-3}/0.02708)^{1.4-1}(2273.15\ K)$
$T_4 = 1132.0050\ K$

$W_{net} = nCp(T_3 – T_2) – nCv(T_4 – T_1)$
$W_{net} = 7/2(8.3145)(2273.15 – 866.01697) – 5/2(8.3145)(1132.005 – 293.15)$
$W_{net} = (23511.9768\ J/mol)(1/29)$
$W_{net} = 810.7578\ kJ/kg$

39. Mean effective pressure is the ratio of the net work to the difference of the maximum and minimum volume.

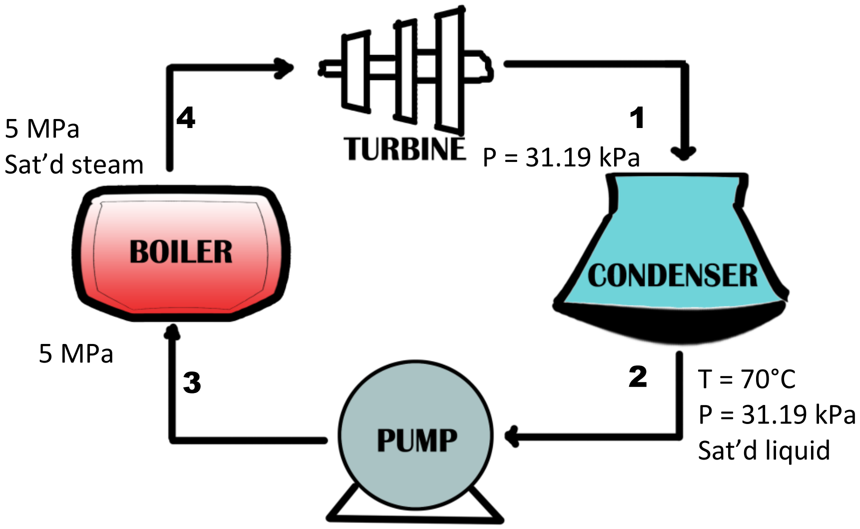
$MEP = W_{net}/(V_{max} – V_{min})$
Using the data obtained above,
$MEP = 23511.9768/(0.02708 – 1.8055 \text{ X } 10^{-3})$
$MEP = 930.2648\ kPa$

40. Cut-off ratio is the volumetric ratio of the states 3 and 2. Since the gas is ideal and it obeys Boyle's Law, then the ratio in temperatures as well as volumes will be the same
$r_c = V_3/V_2 = T_3/T_2 = 2273.15/866.01697$
$r_c = 2.6244$

To check using the volumes:
$r_c = 4.7392 \times 10^{-3}/1.8055 \times 10^{-3}$
$r_c = 2.6249$
Answers are the same!

43-46. Rankine Cycle

1 to 2: Constant pressure cooling
2 to 3: Isentropic compression
3 to 4: Constant pressure heating
4 to 1: Isentropic expansion



43. The quality of the steam is the amount of vapor (or liquid) present during the isentropic expansion.

At 4, the entropy of the system comes from the pure vapor from the outlet of the boiler. In this case, the pressure is 5 MPa, and is a superheated steam at 263.99 °C. From the table:
$S_4 = 5.9734$ kJ/kg-K
As the vapor expands, its volume increases, so the pressure decreases. There are several pressures on the table so the value to look at is the pressure given at the condenser, and that is 31.19 kPa.
At 31.19 kPa, 70°C: $S_{1L} = 0.9549$ kJ/kg-K; $S_{1V} = 7.7553$ kJ/kg-K
$S_4 = S_1 = S_{1V}X + (1-X)S_{1L}$ let X = vapor fraction
$5.9734 = 7.7553(X) + (1-X)0.9549$
$X = 0.7380$

This means that the outlet steam is 74% vapor and 26% liquid.

44. The thermal efficiency of a Rankine Cycle is determined by the ratio of the difference of the works of the turbine and pump to the work in the boiler.

$\eta = \frac{Ws\,turbine - Ws\,pump}{QH}$
To solve for the $W_{sturbine}$:
Assuming that flow is constant, and no amount is removed for all the processes:
$W_{sturbine}$: $H_4 - H_1$
$H_4 = 2794.3$ kJ/kg (from the table)
$H_1 = H_{1L}(1-X) + H_{1V}X$
$H_1 = 2626.8(0.7380) + 292.98(1-0.738)$
$H_1 = 2015.2722$ kJ/kg
$W_{sturbine}$: $2794.3 - 2015.2722 = 779.0278$ kJ/kg

To solve for the W_{spump}:
$W_{spump} = VdP = (1 \times 10^{-3}\ m^3/kg)(5 \times 10^6 - 31.19 \times 10^3)$
$W_{spump} = 4.9688$ kJ/kg

To solve for Q_H:

$H_3 = W_{spump} + H_2$ where H_2 is the enthalpy delivered by the pure liquid

$H_3 = 4.9688 + 292.98$

$H_3 = 297.9468$ kJ/kg

Thus, $Q_H = H_4 – H_3$

$\eta = \frac{779.0278-4.9688}{2794.3-297.9468}$

$\eta = 0.3100$

45. Wnet is the work delivered by the differences (or sum, depending on the enthalpy difference one uses) in the turbine and pump.

$W_{net} = W_{sturbine} – W_{spump}$

Since the value of the net work is in kilowatts, there is a mass flow rate incorporated to the enthalpy differences.

500 kW = m(779.0278 – 4.9688) kJ/kg

m = 0.6459 kg/s

46. If the thermal efficiency is changed, by looking at the cycle, only the work on the turbine will be changed. This is because at states 4 and 2, the fluid is at a pure state. At state 3, the combination of 2 and the work in pump is not affected by the fraction of vapor since the work in the pump is a function of the specific volume (assumed constant for the two differential pressures) and the pressure.

$\eta = 0.25$

$0.25 = \frac{Ws\ turbine-4.9688}{2794.3-297.9468}$

$W_{sturbine} = 629.0546$ kJ/kg

$H_1 = H_4 - W_{sturbine}$

$H_1 = 2794.3 – 629.0546$

$H_1 = 2165.2454$ kJ/kg

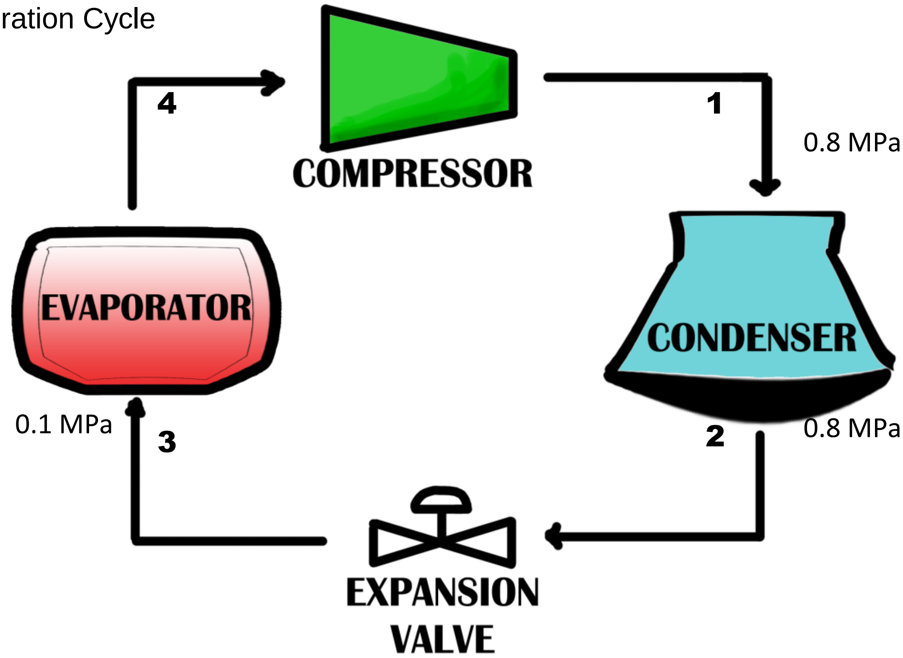
2165.2454 = 2626.8(X) + (1-X)292.98

X = 0.8022

Thus, for a thermal efficiency of 25%, the outlet steam from the turbine is 80% vapor and 20% liquid.

48-50. Refrigeration Cycle

1 to 2:
Constant
pressure
cooling
2 to 3:
Isenthalpic
expansion
3 to 4:
Constant
pressure
heating
4 to 1:
Isentropic
compression



48. The quality of the outlet in the throttling valve can be determined on the assumption that the liquid condenses into pure liquid at 0.8 MPa.

$H_2 = 93.42$ kJ/kg

$H_2 = H_3$

$93.42 = 231.35X + (1-X)16.29$ let X = vapor fraction

$X = 0.3586$

49. Coefficient of performance in a refrigeration cycle is the ratio of the work in the evaporator (Q_B) to the compressor (W_c).

On the assumption that the no fluid is lost during the cycle, and the evaporator produces a pure vapor,

$Q_B = H_4 - H_3$

$W_c = H_4 - H_1$

At 0.1 MPa,

$H_4 = 231.35$ kJ/kg

$H_3 = 93.42$ kJ/kg

At 0.8 MPa, the fluid undergoes isentropic compression

$S_4 = 0.9395$ kJ/kg-K (from the table, pure vapor)

$S_4 = S_1$

$0.9395 = X(0.9374)$ (X is the vapor fraction)

$X = 1.0022$

This value signifies that more vapors are produced during such compression.

Why use the first data on the table?

During compression, the pressure is increased and there are four other data which have higher pressures. In fact, all these data can be used to solve the value for X. Usually, in refrigeration cycles, X is greater than 1. This makes the last two data on the table insignificant. Now we are left with two data.

Intuitively, if the steam condenses then it must come from a higher temperature because technically, you will not add a condenser to a system if it can be condensed at the outlet of a compressor. This eliminates the value for the saturated steam, and you are left with the first data on the superheated steam.

H_1 = 1.0022(273.66)
H_1 = 274.2731 kJ/kg

C.O.P. = $\frac{H_4-H_3}{H_1-H_4} = \frac{231.35-93.42}{274.2731-231.35}$
C.O.P. = 3.2134

50. If the cycle will have its expansion valve replaced by an expansion turbine, the process will slightly be different. Instead of the isenthalpic expansion, this will become an isentropic expansion.

Assuming that the condenser produces a pure liquid, then S_2 is the pure liquid.
S_2 = 0.3458 kJ/kg-K
H_2 = 93.42 kJ/kg-K
$S_2 = S_3$
0.3458 = 0.9395X + (1-X)0.0678
X = 0.3190
H_3 = 16.29(1-0.3190) + 231.35(0.3190)
H_3 = 84.8763 kJ/kg

Assuming that everything that comes out from the evaporator is a pure vapor,
S_4 = 0.9395 kJ/kg-K
H_4 = 231.35 kJ/kg
H_1 = 274.2731 kJ/kg (Solved previously from no. 49.)

The coefficient of performance in a refrigeration cycle is determined by the ratio of the work on the evaporator to the difference of the works in the turbine and the condenser.

C.O.P. = $\frac{QH}{WC-WT} = \frac{H_4-H_3}{WC-WT} = \frac{231.35-84.8763}{(274.2731-231.35)-(93.42-84.8763)}$

C.O.P. = 4.2605

C. Reaction Kinetics

2. Rate determines how fast a reactant is converted into a product. Thus if the initial amount of reactant is assumed constant, for different reaction rates, the parameter determining the rate is the specific rate constant (k).

Same thing also happens in a reversible reaction. The conversion goes farthest to a reaction whose k_1 (forward) is greater than k_2 (reverse). If k is the equilibrium constant, then it should be greater to have a higher conversion.

Answer: $k = 10^2$

14. The reaction is elementary: $r_A = -kC_AC_B^2$

Thus the overall reaction order is the coefficients of A and B.

$n = 3$ (third order)

15. The volume of the above reaction is reduced to half, thus, $C_{Af} = 2C_A$ and $C_{Bf} = 2C_B$

$n = 2C_A(2C_B)^2 = 8C_AC_B$

It is increased 8 times.

16. By looking on the elementary reaction 2dA/dt = dB/dt, by the virtue of their stoichiometric coefficient. Since dA/dt = rA, then rB = 2rA

23. Using the given reaction: $A + 2B \longrightarrow 2C$

$r_A = -kC_A^nC_B^m$

If C_A is doubled, rate doubles: $2r_A = -2kC_A^nC_B^m$. Substitution to the first equation, $2C_A^n = 2C_A^n$. Thus n = 1. $4r_A = -2kC_AC_B^m$. Substitution to the original equation, $4C_B = (2C_B)^m$. Thus m = 4.

$-r_A = kC_AC_B^2$

30. Reaction is in first order, CSTR with two tanks in series.

V = 400 000 L $\%X_{AF} = ?$

Vo = 100 L/hr

$t_{1/2} = 24$ hours

$k = \ln 2/t_{1/2} = 0.028888$ /hr

For the first conversion in the tank: where $\tau = V/vo$

$k\tau = (C_{Ao} – C_A)/C_A$

$C_A = 8.58188 \times 10^{-3}\ C_{Ao}$

Then use the C_A as the new feed to compute for C_f.

$115.5556 = (C_A – C_f)/C_f = [(8.58188 \times 10^{-3})C_A – C_f]/C_f$

$C_f = 7.33452 \times 10^{-5}\ C_{Ao}$

$X_{AF} = 1 - C_{AF}/C_{Ao} = 1 – 7.33452 \times 10^{-5}$

$X_{AF} = 0.9999$ or 99.9927%

If the given would have been changed to V = 40, 000 L, then the answer is 99.3655%, which is the answer in the problem.

31. The reaction is in second order.
C_A = 0.03 mol/L
Rate = 3 x 10^{-3} $M^{-1}s^{-1}$
If C_A = 0.015 M,
Rate = kC_A^2
k = $3x10^{-3}/(0.03^2)$ = 3.3333
Rate = $3.3333(0.015)^2$
Rate = 7.5 x 10^{-4} $M^{-1}s^{-1}$

32. Reaction is first order.
k = 3 x 10^{-3}/s
$t_{1/2}$ = ln2/k = ln2/3 x 10^{-3}/s
$t_{1/2}$ = 231.0491 s

33. Reaction is first order.
At t = 30 mins, C_A = 0.15 M, C_{Ao}= 0.55 M
t = ? (For the same condition where C_A = 0.15 and C_{Ao} = 0.35)
ln(0.55) – ln(0.15) = k(30)
k = 0.043309
ln(0.35) – ln(0.15) = 0.043309(t)
t = 19.5640 min

34. Activation energy is the energy required for a substance to undergo a chemical reaction upon collision with the other reactants. Because no specific type of reaction is given, we'll assume that it follows Arrhenius Equation.

Ea = 125 kJ/mol
k_1 = 0.033/s, T_1 = 55°C
k_2 = ?, T_2 = 100°C
$\ln|k_2/k_1| = -\frac{Ea}{R}(1/T_2 - 1/T_1)$
k_2 = 8.2791/s

35. Because no specific type of reaction is given, we'll assume that it follows Arrhenius Equation.

k_1 = 4.27 x 10^{-3}/s, T_1 = 25°C
k_2 = 7.35 x 10^{-2}/s, T_2 = 80°C
$\ln|k_2/k_1| = -\frac{Ea}{R}(\frac{1}{T_2} - \frac{1}{T_1}) = \ln|7.35 \times 10^{-2}/4.27 \times 10^{-3}| = -(Ea/8.3145)(1/353.15 - 1/298.15)$
Ea = 45.2952 kJ/mol

36. This problem can be solved by dimensional analysis. Because the order of reaction is given, it provides us with the value of n. If not, the reaction shall be written in with its rate law to come up with the correct expression.

Third order reaction.
k_c = 2.65 x 10^4 $M^{-2}s^{-1}$ at T = 30 °C, P = 1 atm.
$K_p = k_c(RT)^{-n} = 2.65[(0.08206)(30+273.15)]^{-3}$
K_p = 1.7214 $M/atm^{-3}s$

37. Isothermal, irreversible aqueous phase reaction in a CSTR.

$A + B \longrightarrow E$

T = 100°F

$dC_E/dt = r_E = kC_AC_B$ $\quad$ $k = 15\ ft^3/lbmol\text{-}h$

$V = 1000\ ft^3$

$Vo = 2000\ ft^3/h$

$C_E = ?$

$C_{Ao} = C_{Bo} = 0.25\ lbmol/ft^3$

Because the reaction provides the same amount of species, it will give us a rate = $kC_AC_B = kC_A^2$ assuming that it is an elementary reaction.

$\tau = v/vo = 1000/2000 = 0.5$ hour

In a CSTR of a second order reaction:

$k\tau = \frac{C_{Ao}-C_A}{C_A{}^n}$ = where k =15, τ = 0.5, $C_{Ao} = 0.25$

$15(0.5) = \frac{0.25 - C_A}{C_A{}^2}$

$C_A = 0.12770\ lb\text{-}mol/ft^3$

Then, $dC_E/dt = kC_AC_B$

$C_E = ktC_AC_B = 15(0.5)(0.12770)(0.12770)$

$C_E = 0.1223\ lb\text{-}mol/ft^3$

38.

39. The reaction is a consecutive reaction where both the specific rate constants are the same.

$k_1 = k_2 = 0.35/hr$

$C_{Ao} = 2.5\ lb\text{-}moles/ft^3$ $\quad$ $C_{Bo} = C_{Co} = 0.5\ lb\text{-}moles/ft^3$

PROBLEM A

The time in which B is maximized is when the disappearance is least and the production is greatest. Thus, B should be evaluated at any time that will provide the maximum.

$dC_B/dt = k_1C_A - k_2C_B$

$dC_B/dt = k(C_A - C_B)$

Applying Differential Calculus for Maxima:

$0 = kdC_A - kdC_B$ $\quad$ $dC_A = dC_B$ $\quad$ where dC_A can be obtained

$dC_A = kC_Adt$ $\quad$ $dC_A/C_A = kdt$ $\quad$ $\ln|C_{Ao}| - \ln|C_A| = kt$

$C_A = C_{Ao}e^{-kt}$

$dC_B/dt = C_{Ao}e^{-kt} - kC_B =$ $\quad$ $dC_B/dt + kC_B = kC_{Ao}e^{-kt}$ $\quad$ [This equation is a Bernoulli equation]

$IF = e\int kdt = e^{kt}$

$IF(C_B) = \int kC_{Ao}e^{-kt}dt(IF)$ = $e^{kt}(C_B) = kC_{Ao}$ = $C_B = ke^{-kt}C_{Ao} + Ie^{-kt}$

When t = 0, $C_{Bo} = Ie^0$; $I = C_{Bo}$

Since $dC_A = dC_B$

$C_{Ao} - C_A = C_{Bo} - C_B + ktC_{Ao}$

$C_{Ao}(1\text{-}e^{-kt} \text{-}kt)= C_{Bo} - e^{-kt}(ktC_{Ao} + C_{Bo})$

$C_{Ao}(1\text{-}e^{-kt} \text{-}kt) = C_{Bo} - e^{-kt}(ktC_{Ao} + C_{Bo}e^{-kt})$

$C_{Ao}(1\text{-}e^{-kt} \text{-}kt) + e^{-kt}(ktC_{Ao}) = C_{Bo} - C_{Bo}e^{-kt}$

$C_{Ao}(1\text{-}e^{-kt} - kt + e^{-kt}kt) = C_{Bo}(1\text{-}e^{-kt})$

$C_{Ao}(1\text{-}e^{-kt})(1\text{-}kt) = C_{Bo}(1\text{-}e^{-kt})$ $\quad$ $C_{Bo}/C_{Ao} = 1\text{-}kt$ $\quad$ $0.5/2.5 = 1\text{-}0.35(t)$

t = 2.2857 hours

PROBLEM B

Using the final expression for C_B.

40. The reaction is in second order.

C_{Ao} = 0.10 M which is 20% complete in 40 minutes when reaction temperature is 25°C.

C_{Ao} = 0.10 M which is 40% complete in 35 minutes when reaction temperature is 50°C.

To solve for both the specific rate constants (k) of the reaction of second order:

$1/C_A - 1/C_{Ao} = kt$

$1/[(0.80)0.10] - 1/0.1 = k_1(40)$ $\qquad k_1 = 0.0625\ M^{-1}s^{-1}$

$1/[(0.60)0.1] - 1/0.1 = k_2(35)$ $\qquad k_2 = 0.19048\ M^{-1}s^{-1}$

$\ln|k_2/k_1| = -\frac{Ea}{R}(1/T_2 - 1/T_1)$

$\ln|0.19048/0.0625| = -[Ea/8.3145](1/323.15 - 1/298.15)$

Ea = 35708.25797 J/mol

Ea = 8534.4785 cal/mol

41. The reaction is first order.

C_{Ao} = 1 M with X_A = 0.92.

The present reactor is a plug flow reactor.

For a plug flow reactor in first order, $k\tau = -\ln|1-X_A|$

$k\tau_1 = -\ln|1-0.92|$ $\qquad k\tau_1 = 2.5257$

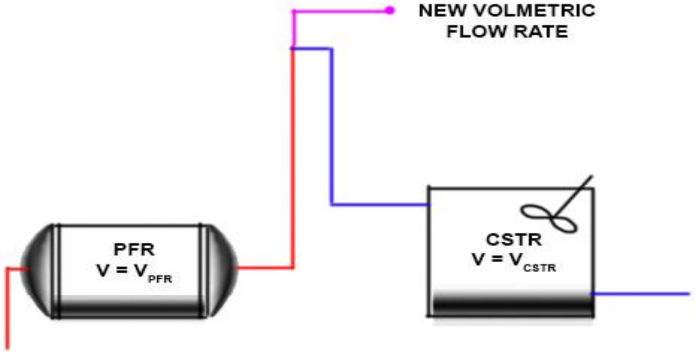
Thus, $vo = kv_{PFR}/2.5257$

For a CSTR in parallel with twice the volume of the reactor, $\tau_2 = v_{CSTR}/vo$. With the assumption that vo is constant, $\tau_1 = v_{PFR}/vo$. And, $v_{CSTR} = 2v_{PFR}$, therefore, $\tau_2 = 2\tau_1$ [1]

First order reaction CSTR:

$k\tau_2 = X_A/(1-X_A)$ $\qquad k\tau_2 = 0.92/(1-0.92) = 11.5$ [2]

Because the given numerical data are insufficient, we have to assume that the specific rate constant is constant since no temperature gradient is present.



$\tau_1 = 2.5257/k$ while $\tau_2 = 11.5/k$ $\qquad$ if substituted with 1, $\tau_1 = 5.75/k$

The two tau's are different since they are representing the two reactors. Eventually, the total capacity is evaluated via the total volumetric flow rate when the outlet flow of the reactors is combined.

$vo = kv_{CSTR}/11.5$ or $vo = kv_{PFR}/5.75$

$vo' = kv_{PFR}/5.75 + kv_{PFR}/2.5257 = kv_{PFR}(0.569843)$

Since $vo = kv_{PFR}(0.395930)$, the increase in capacity is:

$$\frac{\mathrm{kvPFR}(0.569843) - \mathrm{kvPFR}(0.395930)}{\mathrm{kvPFR}(0.395930)}\, x100\%$$

Capacity increase = 43.92525%

And the easiest way to obtain this value is to get the ratio of the PFR to CSTR multiplied to 100%.

Or 1/CSTR divided by 1/PFR multiplied to 100%.

Capacity increase = $k\tau_1$(PFR)/$k\tau_1$(combined) = 2.5257(100%)/5.75

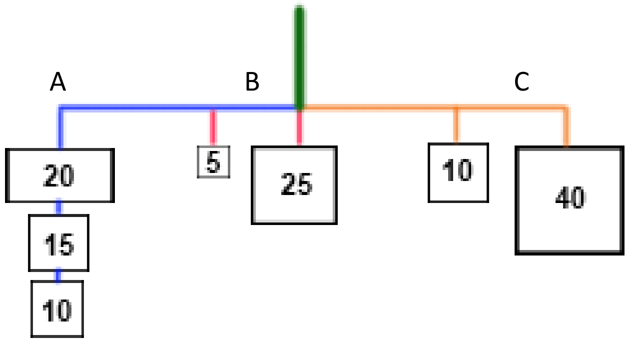
Capacity increase = 43.9252% [The same answer.]

43. This problem is a combination of parallel and series reactors. To come up with a rational answer, several assumptions shall be made.

a. The specific constant for all reactors shall be the same since there is no temperature gradient.

b. The density is constant.

c. The reactor volume relates the residence time for all type.



The total volumetric flow rate is 100 L/min.

For the series reactors in A, we have the total volumetric flow rate for A as:

$V_A = (20+15+10)/(\tau_{A1} + \tau_{A2} + \tau_{A3})$

For the parallel reactors in B:

$V_B = 5/\tau_{B1} + 25/\tau_{B2}$

For the parallel reactors in C:

$V_C = 10/\tau_{C1} + 40/\tau_{C2}$

With the assumptions made, let us provide one value of τ for all, using τ_{C2}.

$\tau_{C1} = 1/4\ \tau_{C2}$

$\tau_{B1} = 1/8\ \tau_{C2}$

$\tau_{B2} = 5/8\ \tau_{C2}$

$\tau_{A1} = 1/4\ \tau_{C2}$

$\tau_{A2} = 3/8\ \tau_{C2}$

$\tau_{A3} = 1/2\ \tau_{C2}$

Thus,

$V_A = (20+15+10)/(\ 1/4\ \tau_{C2} + 3/8\ \tau_{C2} + 1/2\ \tau_{C2}) = 40/\tau_{C2}$

$V_B = 5/(1/8)\ \tau_{C2} + 25/(5/8)\ \tau_{C2} = 80/\tau_{C2}$

$V_C = 10/(1/4)\ \tau_{C2} + 40/\tau_{C2} = 80/\tau_{C2}$

$V_T = V_A + V_B + V_C$

100 L/min = $40/\tau_{C2} + 80/\tau_{C2} + 80/\tau_{C2} = 200/\tau_{C2}$

τ_{C2} = 2 minutes

45. The reaction is in gas phase with no particular order takes place in a CSTR.

60% A, 20% B, 20% Inerts

C_{Ao} = 0.50 M; C_A = 0.10 M

The reaction order and the residence time do not matter since the reaction has a variable density which can be used to calculate the conversion directly.

$\varepsilon_A = \frac{v_{=1}-v_{=0}}{v_{=0}}$ This is the expression used to relate the volumes (or concentrations) in a particular reaction. It is the difference on the volumes between the fully converted reactant to the unreacted species.

The reaction: $2A + B \rightarrow R$ gives us:

$$\varepsilon_A = \frac{\frac{60}{2}-\frac{60}{2}+20+20-100}{100} = -0.60$$

$$X_A = \frac{C_{Ao}-C_A}{C_{Ao}+\varepsilon_A C_A} = \frac{0.50-0.10}{0.50+-0.60(0.10)} = 0.90909090$$

% Conversion is 90.9090%

46. The liquid fed is a pure A: C_{Ao} = 1M. It passes through two reactors: V = 2L each.

$r_A = 0.05C_A^2$ Ms^{-1} C_{Af} = 0.50 M

For a two CSTR in series:

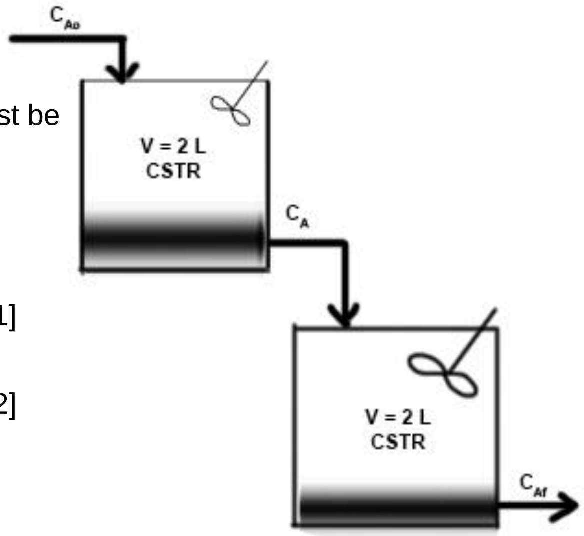
In this reaction, n = 2.

k = 0.05

To obtain vo:

$V_o = v_T/\tau$

Thus, for every tank, residence time must be obtained.



For a second order reaction CSTR,

$$k\tau = \frac{C_{Ao}-C_A}{C_A^2}$$

$$0.05(\tau_1) = \frac{1-C_A}{C_A^2} \qquad [1]$$

Then, on the second tank:

$$0.05(\tau_2) = \frac{C_A-0.50}{0.50^2} \qquad [2]$$

Since the density is constant, the residence time for both reactors are the same: $\tau_1 = \tau_2$

Equating 1 and 2:

$$\frac{C_A-0.50}{0.50^2} = \frac{1-C_A}{C_A^2}$$

$$C_A = 0.6766\ M$$

Substitution to either equation, $\tau_1 = \tau_2$ = 14.12840 seconds = 0.2355 minutes

$V_o = v_T/\tau$

Vo = (2 L + 2L)/(0.2355 minutes + 0.2355 minutes)

Vo = 8.4935 L/min

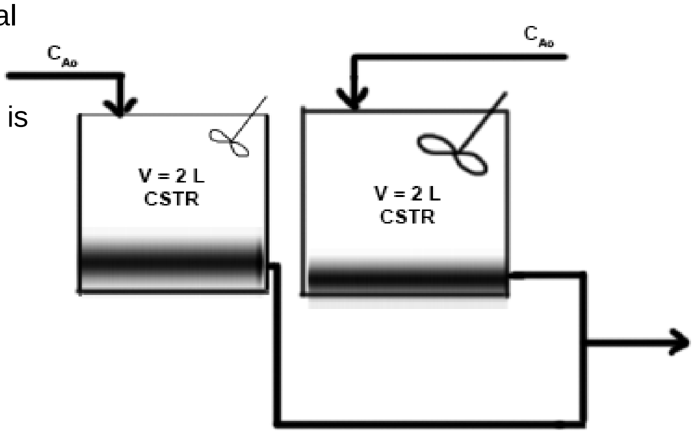
47. If the tank in Number 46 is in parallel:
Vo is computed by adding the individual volumetric flow rate of each tank:

For the first CSTR using the fact that it is converted to product for just one tank:

$k\tau = \frac{C_{Ao}-C_A}{C_A{}^2}$

$(0.05)\tau_1 = \frac{1-0.5}{0.5^2}$

τ_1 = 40 seconds = 2/3 minute.



Because the tank has the same volume, with constant density for the fluid:

$\tau_1 = \tau_2$ = 40 seconds = 2/3 minute.

Thus, $Vo = 2/\tau_1 + 2/\tau_2$ = 2 L/(2/3)minute + 2 L/(2/3) minute

Vo = 6 L/min

48. If the reactors arranged in parallel are changed into PFR:
The expression for a second order will be:

$(n-1)C_{Ao}{}^{n-1}k\tau = {\frac{C_A}{C_{A_o}}}^{1-n} - 1$ $\qquad C_{Ao}k\tau = {\frac{C_A}{C_{A_o}}}^{-1} - 1$

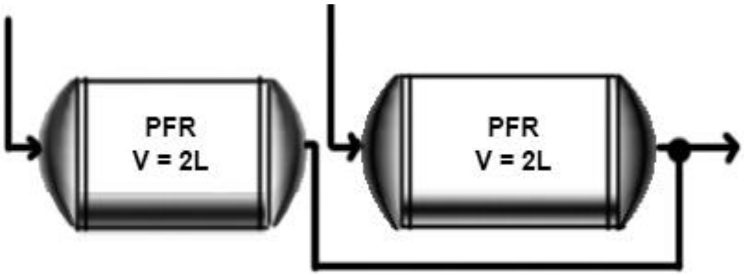
For the first reactor:

$1(0.05)(\tau_1) = \left(\frac{0.5}{1}\right)^{-1} - 1$ $\qquad \tau_1$ = 20 seconds = 1/3 minute

For the second reactor, since they have the same residence time, τ_2 = 20 seconds = 1/3 minute.

Vo = 2 L/(1/3)minute + 2 L/(1/3)minute

Vo = 12 L/min



49. If two plug flow in series will be used, the expression for a second order will be:

$(n-1)C_{Ao}{}^{n-1}k\tau = {\frac{C_A}{C_{A_o}}}^{1-n} - 1$ $\qquad C_{Ao}k\tau = {\frac{C_A}{C_{A_o}}}^{-1} - 1$

For the first reactor:

$1(0.05)(\tau_1) = {\frac{C_A}{1}}^{-1} - 1$ $\qquad 0.05(\tau_1) + 1 = C_A{}^{-1}$ [1]

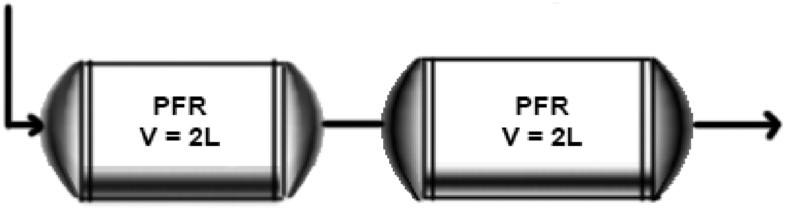
For the second reactor:

$1(0.05)(\tau_2)= \left(\frac{0.5}{C_A}\right)^{-1} - 1$ $\quad\quad$ $(0.05)(\tau_2) + 1= \left(\frac{0.5}{C_A}\right)^{-1}$ $\quad\quad$ [2]

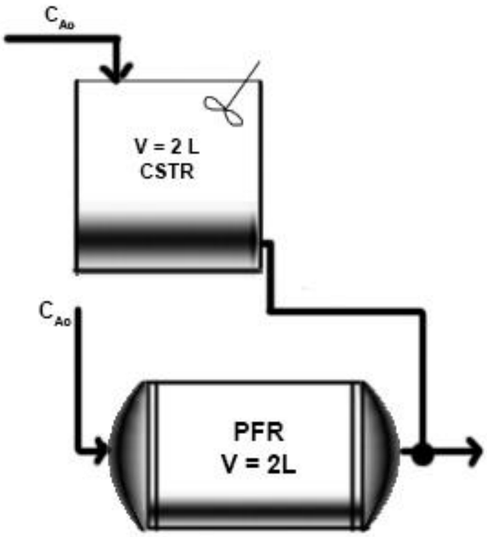
Equating [1] and [2]:

${C_A}^{-1} = \left(\frac{0.5}{C_A}\right)^{-1}$ $\quad\quad$ $C_A = 0.70711$ M

Substituting this value to either 1 or 2, $\tau_1 = \tau_2 = 8.2843$ seconds = 0.13807 minutes.
$V_o = v_T/(\tau_1 + \tau_2)$
Vo = (2 L + 2 L)/(0.13807 + 0.13807)minutes
Vo = 14.4853 L/min



50. This time, two different types of reactors of the same volume are hooked up in parallel:



Using the data computed on numbers 47 and 48:
For the CSTR Tank, τ_1 = 2/3 minute.
For the PFR Tank, τ_2 = 20 seconds = 1/3 minute.

Thus, $v_o = v_1/(\tau_1) + v_2/(\tau_2)$
Vo = 2L/(2/3) minute + 2L/(1/3) minute
Vo = 9 L/min

D. Unit Operations

1. Fluid Mechanics

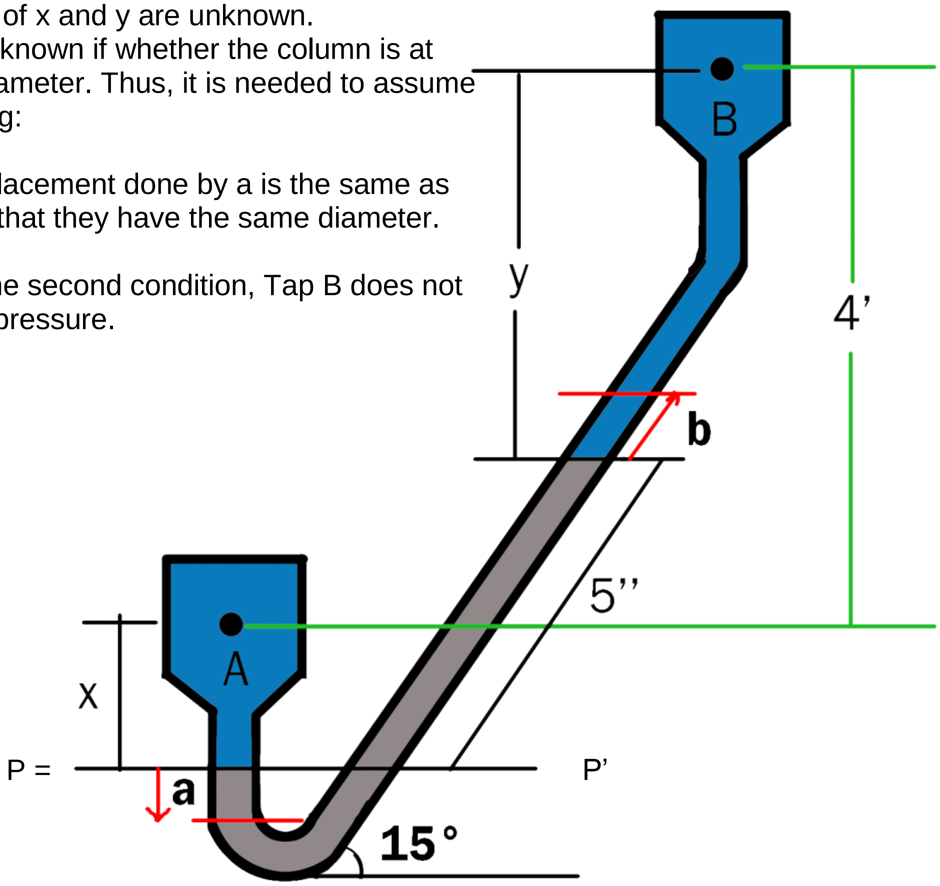
1. Because the pool is exposed to the atmosphere, it is contributory to the total pressure.
$P = \rho gh + P_{Atm}$
$P = (1000)(9.81)(2) + 101325$
$P = 120945$ Pa or 120.945 kPa

2. The problem states that Tap B is 4’ higher than Tap A. Practically, this should be assumed at the point where the fluid is coming from. And here, the center of the tap will be the basis. The mercury level would be assumed to align lower than the Tap A since it will just move higher if it is on top, and no changes in level for Mercury will be observed.

The values of x and y are unknown.
It is also unknown if whether the column is at constant diameter. Thus, it is needed to assume the following:

1. The displacement done by a is the same as b provided that they have the same diameter.

2. During the second condition, Tap B does not change its pressure.



$P' = (6/14.7)(101325) + 9.81(1000)y + 5(2.54)\sin 15°(9.81)(13500)/100$
$P' = 45710.28379 + 9810y$ [1]

$P = P_A + xg\rho H_2O \qquad = P_A + (9.81)(1000)x$
$P = P_A + 9810x$
$P = P'$

$P_A + 9810x = 45710.28379 + 9810y$
$P_A - 45710.28379 = 9810(y-x)$ [2]

$P_f = P_A' + (a+x)g\rho H_2O$
$P_f = P_A + 2(101325)/14.7 + (a+x)(9.81)(1000)$
$P_f = P_A + 13785.71429 + 9810(a+x)$ [3]
$P_f' = P_B + (y-b\sin\alpha)g\rho H_2O + [(rm+b)\sin\alpha + a]\, g\rho Hg$
$P_f' = 41357.14286 + (y-b\sin15°)(9.81)(1000) + [5(2.54)\sin15°/100 + b\sin15° + a)(9.81)(13500)]$
$P_f' = 41357.14286 + 9810y - b\sin15°(9810) + 4353.14093 + 132435b\sin15° + 132435a$
$P_f' = 45710.28379 + 9810(y-b\sin15°) + 132435(a + b\sin15°)$ [4]
Evaluate [3] = [4]

$P_A + 13785.71429 + 9810(a+x) = 45710.28379 + 9810(y-b\sin15°) + 132435(a+b\sin15°)$
$9810(y-x) + 45710.28379 + 13785.71429 + 9810(a+x) = 45710.28379 + 9810(y-b\sin15°) + 132435(a+b\sin15°)$
$13785.71429 = 122625(a+b\sin15°)$

With the assumptions made from the beginning of the solution, for constant diameter: a = b.

$0.11242 = a + b\sin15°$
a = b = 3.51598 inches.
The new reading along the manometer is 12.0320 in Hg.

3. H_2O at 20°C.
$d_1 = 1''$ $d_2 = ½''$
$P_1 = 10$ psig
$z_1 - z_2 = 40$ ft
Q = 30 GPM

Using Bernoulli's Equation:

$$\frac{P_2 - P_1}{\rho} + g\Delta z + \frac{{v_2}^2 - {v_1}^2}{2} = \sum F$$

To find v_2:
$A_2 = [0.5(2.54)/100]^2\pi/4 = 1.26676 \times 10^{-4}\ m^2$
$v_2 = 113.5624/[1000(60)(1.26676 \times 10^{-4)}] = 14.94117$ m/s
$v_1 = 3.7353$ m/s

Using Bernoulli's Equation:

$$\frac{101325 - \frac{10 + 14.7}{14.7}(101325)}{1000} + (9.81)(-40)(12)(2.54)\frac{1}{1000} + \frac{3.7353^2 - 14.94117^2}{2} = \sum F$$

$\sum F = 293.17515\ kgm^2/s^2$
$\sum F = 27.2369\ kgft^2/s^2$

5. GPM = 40
Z = 40 ft
$\eta = 0.65$
BHP = GPM(lift)/3956η
BHP = 40(40)/3956(0.65)
BHP = 0.6222

6. Q = 25 m^3/h
ID = 60 mm

$$v = \frac{25}{(3600)\left(\frac{60}{1000}\right)^2 \frac{\pi}{4}}$$

v = 2.4561 m/s

8. $r_H = \frac{2ab}{(a+b)} = \frac{wetted\ area}{wetted\ perimetrer}$
$r_H = \frac{4(1.5)}{4+1.5}$
$r_H = 2.1818$ m

9. ID → 2ID
At Constant Q,
$\Delta P = ½(v_2^2 - v_1^2)$
Thus, ΔP is reduced to $(¼)^2/2$
ΔP = (1/32)ΔP

10. For pumps in series arrangement, the discharge changes by a factor of unity (1).

11. For pumps connected in parallel, v changes by v/a + v/b. If a = b, then 2v/a. Thus, the system produces doubled (2) capacity.

12. Using the same pressure drop equation relating to the velocity, $\Delta P = (v_2^2 - v_1^2)$, the velocity when doubled, $(2)^2 = 4$

15. NPSH = 8 ft
H_2O at 25°C
Δz = ?
$h_{fs} = 3.8$ ft
at 25°C, VP = 3237.855 Pa
Surface is vented, thus exposed to atmosphere.

$$NPSH = \frac{Po - vP}{\rho} - hfs + \Delta z$$

$$8\text{ ft} = \frac{14.7(144) - \frac{3237.855}{101325}(14.7)(144)}{62.43} - 38 + \Delta z$$

$\Delta z = 21.0233$ ft

16. $\mu_{oil} = 30$ cp
$\rho = 60\ lb/ft^3$
ID = ½’’
v = ?
Laminar = 2100

$N_{Re} = \frac{vD\rho}{\mu}$

$2100 = 60(0.5)(1/12)[(30)(6.7197 \times 10^{-4})](v)$

$v = 16.9336$ ft/s

17. $T_{H2O} = 60°F$

ID = 3''

$N_{Re} = 353\ 000$

Using Perry's Chemical Engineers Handbook, Figure 10-13.

$V_{ave}/V_{max} = \phi[N_{Re,max}, N_{Re,min}]$

$V_{ave}/V_{max} = 1/0.82$

$V_{ave}/V_{max} = 1.2195$

18. Using Bernoulli's Equation:

$$\frac{(14.7-20)144}{62.43} + 100 = \frac{{v_2}^2}{2(32.174)}$$

v = 75.1542 ft/s

$Q = 75.1542(\frac{(6/12)^2\pi}{4})$

$Q = 14.7565$ ft^3/s

19. $P_{Theo} = 3.45$ hp

P_{cost} = PhP. 3.73/kWh

ε = 65%

Operation: 12 hours a day

3.25(746) = 2424.5 W = 2.4245 kW

2.4245(12) = 29.094(30) = 872.82 kWh

Total Cost = 872.82(3.73)/0.65

Total Cost = PhP. 5008.6440

20. By the virtue of the Affinity Laws, the discharge (Q) is directly proportional to the impeller speed (N) of the pump. Thus, when the speed is doubled, flow rate is also doubled.

34.

35. The variable area meter is a rotameter.

S.G. = 8.0

v = 3 m^3/min

max flow rate = ?

From Perry's Chemical Engineers Handbook, equation 10-38:

$$\frac{Q_A\rho_A}{Q_B\rho_C} = \frac{K_A}{K_B}\frac{\sqrt{(\rho_f-\rho_A)\rho_A}}{\sqrt{(\rho_f-\rho_B)\rho_B}}$$

Since no ratio has been given, in this problem, we assume that $K_A/K_B = 1$.

$$\frac{Q_A}{Q_B} = \frac{1.59\sqrt{(8-1)(1)}}{1\sqrt{(8-1.59)(1.59)}}$$

$Q_B = 3/1.31771$
$Q_B = 2.2767\ m^3/min$

37. T = 80°F
v = 10 ft/s
D = 6'' Schedule 40 Steel Pipe
L = 1000 ft

Using the value from Perry's Chemical Engineers Handbook:
$\rho_{300\ K} = 995.6854\ kg/m^3$
At 300 K:
$\mu H_2O = 8.5384 \times 10^{-4}$ Pa-s
$N_{Re} = \frac{vD\rho}{\mu}$
$N_{Re} = (10/3.28)(995.6854)\{[6.0.65(2.54)]/100\}(8.5384 \times 10^{-4})^{-1}$
$N_{Re} = 547\ 691.9033$

38. $T_1 = 70°F$
$T_2 = 170°F$
ΔP = 1'' H_2O
$v_{ave} = 20$ ft/s
cp = 0.24 BTU/lbm°F, Perfect gas

Q = mcpΔT
Q = 0.24(170-70)
Q = 24 BTU/lbm

39. Natural gas at T = 70°F
ID = 12''
$P_1 = 30$ atm
$P_2 = 15$ atm
ΔL = 400 miles
M = 17 g/mol
μ = 0.01 cp
v = ? (ft^3/hr or m^3/hr) at 1 bar

By converting some of the given, T = 294.2611 K, ΔL = 643.7376 km

The Hagen-Poiseuille Equation will be used for such a gas:
$P_1^2 - P_2^2 = 4f\Delta LG^2RT/(PM)$
Incorporating the mass flow rate:
$$m = \frac{\pi D^4 M({P_1}^2 - {P_2}^2)}{128RT\mu(L_2 - L_1)}$$
$$m = \frac{\pi\left[\frac{12(2.54)}{100}\right]^4(17)\{[(30)(101325)]^2 - [(15)(101325)]^2\}}{128(2)(8314.5)(294.2611)(643.7376\ x\ 10^3)(0.01/1000)}$$
m = 46.605 kg/s
$\rho_1 = P_1M/(RT)$

ρ_1 = 30(101325)17/[8314.5(294.2611)] = 21.12116 kg/m^3
ρ_2 = P_2M/(RT) = 15(101325)17/[(8314.5)(294.2611)] = 10.5605 kg/m^3

ρ_{ave} = 15.8408 kg/m^3
Q_1 = 46.605/15.8408 = 2.9421 m^3/s = 10591.5105 m^3/hr = 373 748.4786 ft^3/hr
The correct answer should be reported as stated above.
Below is the answer from the book, which comes from the lower density of the gas.
Q_2 = 46.605/10.5605 = 4.4131 m^3/s = 560 624.4874 ft^3/hr

40. μ_k = 0.000043 m^2/s
L = 50.2 cm
ṁ = 0.03 kg/s
ρ = 955 kg/m^3
ΔP = 4.77 atm
ΔP = 128LQμ/(πD^4)
Q = ṁ/ρ = 0.003 kg/s/955 kg/m^3 = 3.14136 x 10^{-6} m^3/s

Using the Hagen-Poiseuille Equation, $\Delta p = \frac{128\,LQ\mu}{\pi D^4}$
$(4.77)(101325) = \frac{128(50.2/100)(3.14136\ X\ 10^{-6})(0.00043)(955)}{\pi D^4}$
D = 1.5235 mm
R = 0.76177 mm

42. From Perry's Chemical Engineers Handbook, Figure 10-38:
Efficiency of 5'', 129 GPM pump: 75%
Efficiency of 4.5'', 140 GPM pump: 77%
Average efficiency = $\frac{75+77}{2} = 76\%$

44. From the Figure 10-46 of Perry's Chemical Engineers Handbook:
N = 880 rpm
V = 300 gal/min
Max head = ?
Head (ft) = 36 ft

45. Q = 500 m^3/hr
$P_{discharge}$ = 0.5 pisa
Power = QP
Power = (500)(0.5)(14.7)$^{-1}$(101325)
Power = 0.4787 kW

46. For the four-stage compressor:
Q = 500 m^3/hr
P = 200 psig
ε = 66%
For ideal gas, PV = nRT
But n will be changed to Q since it is there where the number of moles will be obtained.
PV = 8314.5(25+273.15)(500)(1.1853)/[(29)(3600)]
PV = 14072.4185

W'min = $\frac{N\gamma}{\gamma-1}nRT\left[\left(\frac{P_1}{P_o}\right)^{\frac{\gamma-1}{N\gamma}}-1\right]$

Power = $\frac{4(1.4)}{1.4-1}14072.4185\left[\left(\frac{214.7}{14.7}\right)^{\frac{1.4-1}{4(1.4)}}-1\right]$

Power = 41.5894 kW

$P_{required}$ = 41.5894/η = 41.5894/0.66

$P_{required}$ = 63.0143 kW

47. ID = 4.5''

N = 3450 rev/min

P = 40 ft H_2O

From Figure 10-38 of Perry's Chemical Engineers Handbook:

GPM = 248

49. The flow controller is a weir.

z = 7.8''

Q = $\frac{(0.31)h^{2.5}\sqrt{2g}}{tan\emptyset} = \frac{0.31[7.8(2.54)/100]^{2.5})\sqrt{2(9.81)}}{\tan 45}$

Q = 0.024 m^3/s = 1439.4058 L/min

Q = 380.2508 gal/min

50. D = 2'' Schedule 40

N_{Re} = 1800

ID = 2.067''

N_{Re} = $\frac{vD\rho}{\mu}$

Using the Dombrowski, et. al. equation:

L/D = $0.370e^{-0.148NRe} + 0.0550N_{Re} + 0.260$

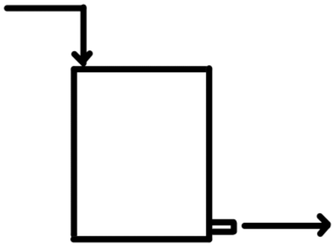
L = 205.17042''

L = 17.0975 ft

51. The Affinity Laws state that the power requirement of the pump is directly proportional to the cube of the speed of the pump.

Thus, if the power requirement is doubled, the speed is increased by a factor of $(2)^3$ = 8.

53. The problem is a draining tank open to the atmosphere.



Since $Q_1 = 0$;

$-V_2A_2 = A_1dZ/dt$

$-\sqrt{2gz}A_2 = A_1\frac{dz}{dt}$

$\sqrt{2g}\frac{A_2}{A_1}\mathrm{dt} = \frac{-dz}{\sqrt{z}}$

$\int_0^t \sqrt{2g}\frac{A_2}{A_1}\mathrm{dt} = \int_{z_1}^{z_2}\frac{1}{\sqrt{z}}\mathrm{dz}$

$\sqrt{2g}\frac{A_2}{A_1}(t) = -2\sqrt{z}\Big|_{z_1}^{z_2}$

t = $\frac{2A_1}{A_2\sqrt{2gc}}\left[{z_1}^{1/2}-{z_2}^{1/2}\right]$

Substitution yields to:

t = $\frac{2(\frac{\pi}{4})}{\left(\frac{1}{12}\right)^2(\frac{\pi}{4})\sqrt{2(32.174)}}\left[4^{1/2}-2^{1/2}\right]$

t = 21.0312 s

54. No ratio for the orifice of tube was given.

ID = 4''
ΔP = 15'' H_2O
S.G. = 0.84
μ = 0.0336 lb/tf-s

The density of oil = 0.84(62.43) = 52.4412 lbm/ft^3
v = $C\sqrt{\frac{2gc\Delta P}{\rho}}$
v = $\sqrt{2(32.174)(78.0824)/52.4412}$
v = 9.7083 ft/s

Q = (4/12)^2(π/4)(9.7083)
Q = 0.8472 ft^3/s
Q = 0.02401 m^3/s
Q = 24.01 L/s
Q = 6.3428 gal/s
Q = 380.5662 gal/min

55. Q = 1200 ft^3/h
ΔP = 30'' Hg
D_2/D_1 = 1/5

To find the change in height:
30" Hg(33.887/29.92) = 33.9776 ft H_2O
Q = $\frac{C_o}{\sqrt{1-\beta^4}}\sqrt{2gc\Delta H}$
Because no C_o is given, it will be assumed as C_o = 0.61

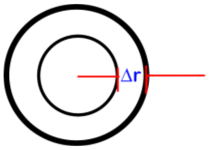
$$\frac{1200}{A_1} = \frac{0.61}{\sqrt{1-(1/5)^4}}\sqrt{2(32.174)(33.9776)}$$

A_1 = 0.0117 ft^2
D_1 = 0.12194 ft
D_1 = 1.46328 inches

This is actually the pipe diameter.

2. Heat Transfer

9.



r_1 = 1 cm
r_2 = 1.8 cm
T_o = 305°C
T_i = 295°C
k varies linearly with T.
k_o = 371.9 W/m-K
b = -9.25×10^{-5} K^{-1}

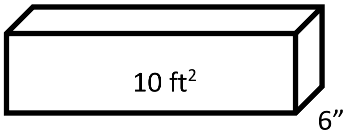
From McCabe’s equation for linear variation of the thermal conductivity,
$k = k_o + bT$
and using the log mean temperature difference between the outside and the inside to account both surroundings,

$$T = \frac{305-295}{ln\left(\frac{305+273.15}{295+273.15}\right)} = 573.1355 \text{ K}$$

$k = 371.9 + -9.25 \times 10^{-5}(573.1355)$
k = 371.8470 W/m-K

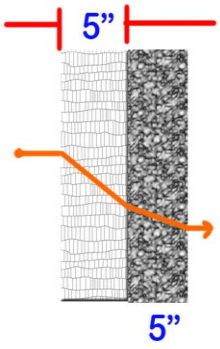
$q = 2\pi Lk\Delta T/\ln|r_2/r_1|$
$q = 2\pi L(371.8470)(305-295)/\ln|1.8|$
q/L = 39748.8349 W/m
q/L = 39.74835 kW/m

13.



Δx = 6”
A = 10 ft^2
k = 0.17 BTU/hr-ft-°F
T_1 = 175°F
T_2= 1300°F
$q = kA\Delta T/\Delta x$
q = 0.17(10)(1300-175)/(6/12)
q = 3825 BTU/hr

14.



$\Delta x = 5''$
$k_1 = 1$ BTU/hr-ft-°F
$k_2 = 0.1$ BTU/hr-ft-°F
$T_o = 500°F$
$T_i = 1500°F$
$q_{TOTAL} = ?$

$q/A = \frac{\Delta T}{\frac{\Delta x}{k_1}+\frac{\Delta x}{k_2}}$
$q/A = \frac{1500-500}{\frac{5/12}{1}+\frac{5/12}{0.1}}$
$q/A = 218.1818$ BTU/hr-ft^2

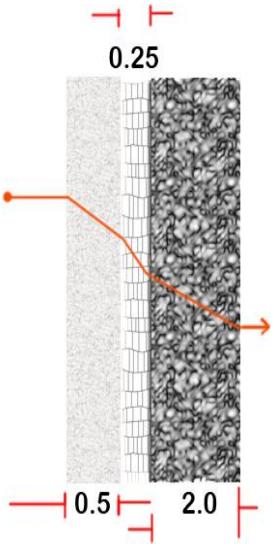
15.
0.7 ft thick fireclay brick, k = 0.6 BTU/hr-ft-°F
Δx insulation, $k_{insulation} = 0.04$ BTU/hr-ft-°F
$T_i = 1800°F$, $T_o = 100°F$

$q/A = \frac{\Delta T}{\frac{\Delta x}{k_1}+\frac{\Delta x}{k_2}}$
$300 = \frac{1800-100}{\frac{0.7}{0.6}+\frac{\Delta x}{0.04}}$
$\Delta x = 0.18$ ft

17.
$k_A = 0.6$ BTU/hr-ft-°F, $\Delta x_A = 0.7$ ft
$k_B = 0.04$ BTU/hr-ft-°F, $\Delta x_B = 0.1$ ft
$T_i = 1800°F$
$T_o = 100°F$

$q/A = \frac{\Delta T}{\frac{\Delta x}{k_1}+\frac{\Delta x}{k_2}}$
$q/A = \frac{1800-100}{\frac{0.7}{0.6}+\frac{0.1}{0.04}}$
$q/A = 463.6364$ BTU/hr-ft^2

18.



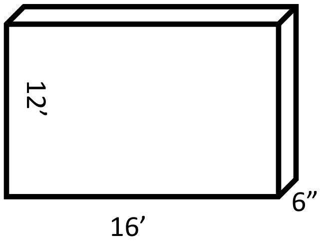
$T_i = 500°C$
$T_o = 50°C$
The thicknesses are given above.
$k_{Al} = 268.08$ W/m-K
$k_A = 0.17$ W/m-K
$k_{RW} = 0.05$ W/m-K

$$q/A = \frac{\Delta T}{\frac{\Delta x1}{k_1}+\frac{\Delta x2}{k_2}+\frac{\Delta x3}{k_3}}$$
$$q/A = \frac{500-50}{\frac{0.5}{100(268.08)}+\frac{0.25}{100(0.17)}+\frac{2}{100(0.05)}}$$
$q/A = 1085.0576\ W/m^2$

19.
k = 0.11 BTU/hr-ft-°F
$T_i = 100°F$
$T_o = 70°F$
$\Delta x = 1.5''$

$q = kA\Delta T/\Delta x$
$q/A = 0.11(100-70)/(1.5/12)$
$q/A = 26.4\ BTU/hr\text{-}ft^2$

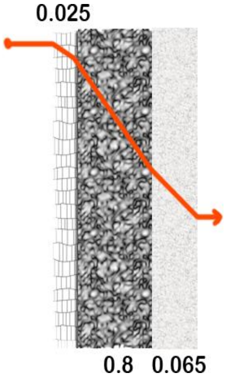
20.



$T_i = 1500°F$
$T_O = 300°F$
k = 0.15 BTU/hr-ft-°F
The thickness is written above, as well as the dimensions of the wall.

$q = kA\Delta T/\Delta x$
$q = (16)(12)(0.15)(1500-300)/(6/12)$
q = 69 120 BTU/hr

21.



$T_i = 40°F$
$T_o = 78°F$
$\Delta x_C = 2"$
$\Delta x_{con} = 6''$
$\Delta x_w = 3"$
The k values in BTU/hr-ft-°F are given above.

The difference in the temperature is proportional to the resistance between the two temperature readings. Thus:

$$\Delta T_1 = \frac{\frac{\Delta xc}{k_C}(To-Ti)}{\frac{\Delta xc}{k_C}+\frac{\Delta xcon}{k_{con}}+\frac{\Delta xw}{k_W}}$$

$$\Delta T_1 = \frac{\frac{2/12}{0.025}(78-40)}{\frac{2/12}{0.025}+\frac{6/12}{0.8}+\frac{3/12}{0.065}}$$

$\Delta T_1 = 22.7453°F$
$T_1 = T_i + \Delta T_1$
$T_1 = 40°F + 22.7453°F$
$T_1 = 62.7453°F$

$$\Delta T_2 = \frac{\frac{3/12}{0.065}(78-40)}{\frac{2/12}{0.025}+\frac{6/12}{0.8}+\frac{3/12}{0.065}}$$

$\Delta T_2 = 13.12230$
$T_2 = T_o – \Delta T_2$
$T_2 = 78°F – 13.12230°F$
$T_2 = 64.8777°F$

36. Since view factors can be solved using the ratio of the volumes of the geometric figures as referred to the sphere,

$F_{21} = V_{sphere}/V_{cube}$
Since L = d,
$F_{21} = (4/3)(\pi)(d/2)^3/d^3$
$F_{21} = 0.5236$

37. Using the Perry's Chemical Engineers Handbook, Figure 5-15:

$$\text{Ratio} = \frac{center\ to\ center\ diameter}{tube\ diameter}$$

$$\text{Ratio} = \frac{6}{2} = 3$$

Direct radiation for 1: 0.49
Direct radiation for 2: 0.23
Total F = Direct radiation 1 &2
Total F = 0.49 + 0.23
Total F = 0.72

38. The equation for Reynolds Analogy is given by:
$\frac{h}{c_p G} N_{Pr} = f/2$ (McCabe)

Since N_{Pr} is given by $C_p \mu / k$
The Reynolds Analogy becomes:
$\frac{h}{kG} \mu = f/2$ [1]

To find the fanning friction factor, we use the data from the Perry's Chemical Engineers Handbook for water at 78°F.
$\rho = 62.2562$ lbm/ft^3
$\mu = 5.9378 \times 10^{-4}$ lbm/ft-s

With the given v = 4ft /s and ID = 2",
$N_{Re} = 62.2562(4)(2/12)/(5.9378 \times 10^{-4})$
$N_{Re} = 69897.7646$

Because the data says that water flows on a smooth horizontal pipe, the fanning friction factor will only be a function of the Reynolds Number at turbulent flow, given by the equation:
$f = 0.079/Re^{0.25}$

$f = 0.079/69897.7646^{0.25}$
$f = 4.8586 \times 10^{-3}$

Using the data from Table 2-413, k = 0.3513 BTU/h-ft-°F.

$G = v\rho = (4)(62.2562) = 249.0248$ lbm/ft^2-s

Substituting all the acquired data on equation [1]:
$h(5.9378 \times 10^{-4})/[(0.3513)(249.0248)] = 4.8586 \times 10^{-3}/2$
h = 357.9121 BTU/hr-ft^2-°F

39. The tube is ¾" BWG
h_i = 20 kW/m^2°C
h_o = 35 kW/m^2°C
k = 120 W/m-K

From Table 11-12 of Perry's Chemical Engineers Handbook:
O.D. = 0.75"
I.D. = 0.584"
x = 0.083"

$$U_o = \frac{1}{\frac{1}{h_i}\frac{D_o}{D_i} + \frac{xD_o}{kDav} + \frac{1}{h_o}}$$

$$U_o = \frac{1}{\frac{1}{20(1000)}\frac{0.75}{0.584} + \frac{0.083(2.54)0.75}{(100)(120)\frac{0.75+0.584}{2}} + \frac{1}{35(1000)}}$$

U_o = 8.8859 kW/m^2-K

42-44: Computing for all the temperature ranges, there should be three answers:

ΔT of hot air: 120 – 100

$\Delta T_{\text{hot air}} = 20°F$

ΔT of cold water: 75 – 60

$\Delta T_{\text{cold water}} = 15°F$

$$\Delta T_{lm} = \frac{\Delta T\text{hot air} - \Delta T\text{cold water}}{ln\frac{\Delta T\text{hot air}}{\Delta T\text{cold water}}}$$

$$\Delta T_{lm} = \frac{20-15}{\ln|20/15|}$$

$\Delta T_{lm} = 17.3803°F$

42. From the solution above, the largest temperature range of the heat exchanger comes from the hot air.

$\Delta T_{\text{hot air}} = 20°F$

43. From the solution above, the smallest temperature range is given by the change in temperature of water.

$\Delta T_{\text{cold water}} = 15°F$

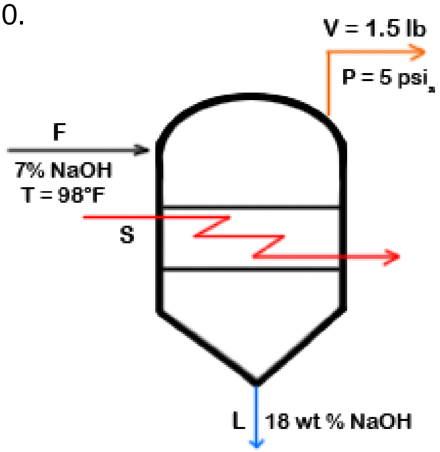
44. As solved above, the log mean temperature difference (LMTD) is:

$\Delta T_{lm} = 17.3803°F$

3. Evaporation

4. From Perry's Chemical Engineers Handbook Equation 11-123:
$BPR = 104.9N^{1.14}$
$BPR = 104.9(0.15+0.1+0.18)^{1.14}$
BPR = 40.0802°F

.
10.



The solution is concentrated in a single effect evaporator. This problem requires data from Duhring's Chart and Merckel's Chart.

Mass Balance:
F = L + V
$F_{xF} = L_{xL}$
F = L + 1.5
(L + 1.5)(0.07) = L(0.18)
L = 0.9545 lb
F = 2.4545 lb

The temperature of the vapor space is also the temperature of the thick liquor.
From Perry's Chemical Engineers Handbook, steam table:
At 5 psi_a, T_v = 161.3611°F (Vapor chest temperature)
H_v = 1130.0626 BTU/lbm

Using Fig 11-124, BPR = 8°F at 18% NaOH, 161.3611°F
$T_{soln} = BPR + T_v = 8 + 161.3611 = 169.3611$°F

From Duhring's Chart,
h_L = 120 BTU/lb (18%, 169.3611°F)
h_F = 60 BTU/lb (7%, 98°F)

Enthalpy Balance:
$q = Lh_L - Fh_F + V(H_v + 0.46BPR)$
q = 0.9545(120) – 2.4545(60) + 1.5[1130.0626 + 0.46(8)]
q = 1667.8839 BTU

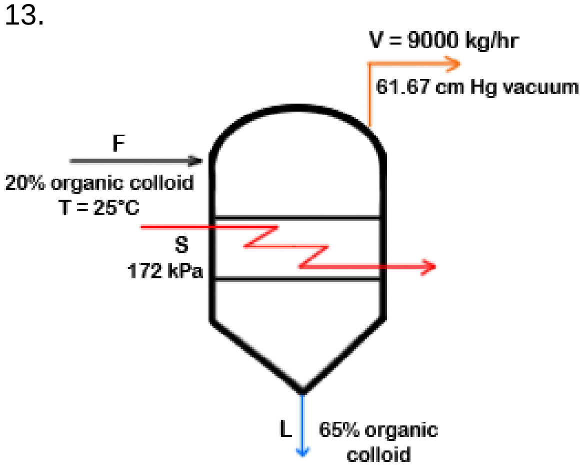
11. For U = 200 BTU/hr-ft-°F,
ΔT = 90°F
A = ?
Using the same conditions, for the mass balance:
1000(0.07) = L(0.18)
L = 388.8889 lb/hr
V = 611.1111 lb/hr

$q = UA\Delta T$; $q = L_{Hl} - F_{hf} + V(h_v + 0.46BPR)$
q = 120(388.8889) + 611.1111[1130.0626 + 0.46(8)] – 1000(60)
q = 679509.3554 BTU/lb
679509.3554 = 200(A)(90)
A = 37.7505 ft^2

12. The scaling of evaporators is related by the expression for which the time is inversely proportional to the square of the heat transfer coefficient.

$1/U^2 \alpha t$
$1/U^2 = kt$
Using extrapolation from the data given:
Let
$f(x)\ [\ 1/545^2, 1/430^2\ ]$
$x\ \ [\ 4.1666, 12.5\ ]$
at x = 0, the start of the operation:
$f(0) = U = 652.8954$ BTU/hr-ft^2-°F

13.



The solution is concentrated in a single effect evaporator. This problem involves specific heat capacities with no BPR.

Mass Balance:
$F = L + V$
$F_{xF} = L_{xL}$
$F = L + 9000$
$(L + 9000)(0.20) = L(0.65)$
$L = 4000$ kg/hr
$F = 13000$ kg/hr

From Perry's Chemical Engineers Handbook:
At 172 kPa, $T_s = 115.3458$°C, and $\lambda_s = 2211.0685$ kJ/kg
At 61.67 cm Hg vacuum, $T_v = 58.7468$°C, and $\lambda_v = 2359.5901$ kJ/kg

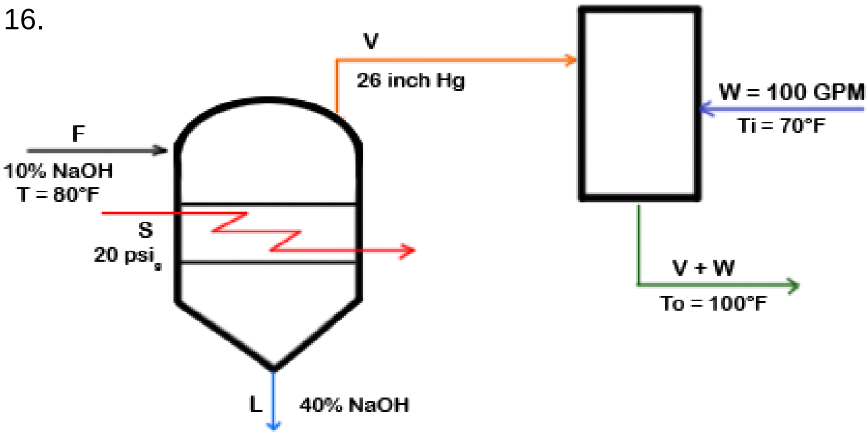
Heat Balance:
Using the given $C_p = 4$J/g°C
$q = FC_p(T_v - T_F) + V\lambda_v$
$q = 13000(4)(58.7468-25) + 9000(2359.5901)$
$q = 22991144.5$ kJ/hr

Since $q = S\lambda_s$
$S(2211.0685) = 22991144.5$
$S = 10398.2054$ kg/hr

14. From the data above, the heating surface area can be determined from the equation
$q = UA\Delta T$
$U = 1800$ W/m^2-K
$22991144.5/3600 = 1800(A)(115.3458-58.7468)/(1000)$
$A = 62.6869$ m^2

15. Economy of an evaporator is given by the ratio of the vapor coming out to the steam used.
$E = V/S$
$E = 9000/10398.2054$
$E = 0.8655$

16.



The solution is concentrated on an evaporator and then the vapor is condensed together with the cooling water. This problem utilizes the Duhring's Chart and Merckel's Chart.

Mass Balance for the Evaporator:
$F = L + V$
$F_{xF} = L_{xL}$
$F(0.10) = L(0.40)$
$F = 6.5L$
$(L + V)(0.10) = L(0.40)$

From Perry's Chemical Engineers Handbook:
At 26" Hg, $T_v = 123.6985°F$, $h_v = 1114.4629$ BTU/lb
At 20 psi$_g$, $T_s = 258.5368°F$, $\lambda_s = 939.3690$ BTU/lb
At 10% NaOH, 80°F, $h_F = 45$ BTU/lb
At 40% NaOH, 123.6985°F, the $T_{sol'n} = 170°F$, thus BPR = 46.3015°F, where $h_L = 150$ BTU/lb

Note: BPR is determined by the condition of the vapor space, i.e. the temperature is equal to that of the liquor if not specified.

To determine V, a heat balance is required for the condenser:
100 GPM = 50081.00076 lb/hr, $c_P = 1$ BTU/lb°F
$q_{in} = q_{out} + Vh_v$
$50081.00076(1)(100-70) = V(1114.4629) + V(1)(32-100)$
$V = 1435.7222$ lb/hr

This expression means that the increase in temperature of water is the sole source of its heat. But for the vapor, it must be brought on its reference temperature to the final temperature to account the change in the vapor phase. The reference temperature 32°F (0°C) is used to signify the start of a liquid phase. The heat balance also includes the energy brought by the enthalpy of the vapor.

Enthalpy Balance for the Evaporator:
From the Mass Balance, and using the acquired value for V, the values of L and F are 478.5741 lb/hr and 1914.2963 lb/hr, respectively.
$q = L_{hL} – F_{Hf} + V(h_v + 0.46BPR)$
$q = (478.5741)(150) – 1914.2963(45) + 1435.7222[1114.4629 + 0.46(46.3015)]$
$q = 1616280.91$ BTU/hr

From the expression q = UAΔT, and given that U = 200 BTU/hr-ft^2°F
1616280.91 = 200(A)(258.5368 –170)
A = 91.2774 ft^2

17. The system is a triple effect evaporator. Here, the change in temperature varies inversely with the heat transfer coefficient
T_3 = 150°F
T_S = 250°F
$OHTC_1$ = 150 BTU/hr-ft^2-°F
$OHTC_2$ = 200 BTU/hr-ft^2-°F
$OHTC_3$ = 250 BTU/hr-ft^2-°F
BPR = 55°F
m = 10000 lb/hr

From Perry's Chemical Engineers Handbook, at T_s = 250°F, λ_s = 945.9506 BTU/lb

$$\Delta T_1 = \frac{\Delta T_{TOTAL}(\frac{1}{U_1})}{\frac{1}{U_1}+\frac{1}{U_2}+\frac{1}{U_3}}$$

Here, the net change in temperature is brought by the change from the steam temperature to the last effect subtracted by all the BPR. [T_S – (T_{V3} + BPR)]

$$\Delta T_1 = \frac{(250-150-55)(\frac{1}{150})}{\frac{1}{150}+\frac{1}{200}+\frac{1}{250}}$$

$\Delta T_1 = 19.1489°F$
A = (10000)(945.9506)/[(150)(19.1489)]
A = 3293.3095 ft^2

19.

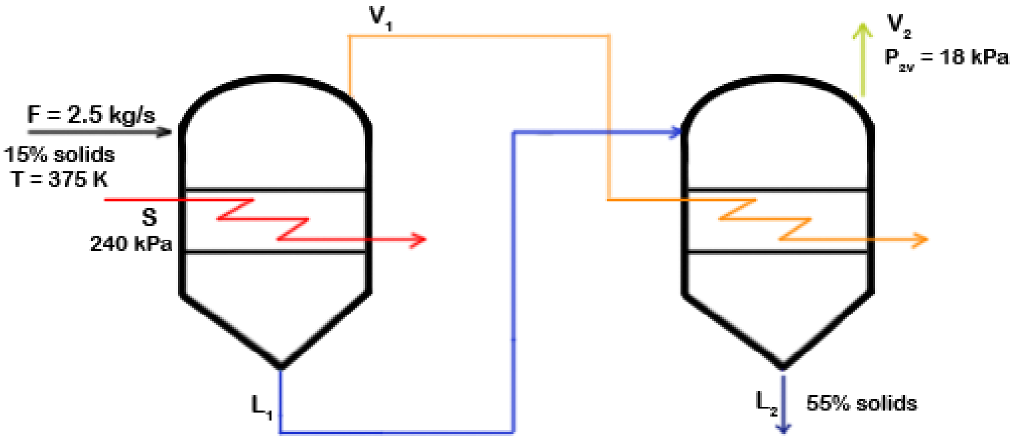
20. The system is a double effect evaporator.
T_s = 250°F
T_V = 120°F
U_1 = 300 BTU/hr-ft^2-°F
U_2 = 250 BTU/hr-ft^2-°F
BPR_1 = 10°F
BPR_2 = 28°F

$$\Delta T_1 = \frac{\Delta T_{TOTAL}(\frac{1}{U_1})}{\frac{1}{U_1}+\frac{1}{U_2}}$$

$$\Delta T_1 = \frac{(250-120-10-28)(\frac{1}{300})}{\frac{1}{300}+\frac{1}{250}}$$

ΔT_1 = 41.8182°F
T_{soln} = 250°F-41.8182°F
T_{soln} = 208.1818°F

21. The system is a double effect evaporator.



Mass Balances

A. For the first evaporator:
$F = L_1 + V_1$
$Fx_F = L_1x_L$
$2.5(0.15) = L_1x_L$
$L_1x_L = 0.375$

B. For the second evaporator:
$L_1 = L_2 + V_2$
$L_1x_L = L_2x_{L2}$
$0.375 = L_2(0.55)$
$L_2 = 0.6818$ kg/s

$V_2 = L_1 – L_2 = F – V_1 – L_2 = 1.8182 – V_1$
From Perry's Chemical Engineers Handbook,
At 240 kPa, $T_S = 399.1275$ K, and $\lambda_s = 2184.6228$ kJ/kg
At 18 kPa, $T_{V2} = 330.7890$ K, and $\lambda_{v2} = 2362.7913$ kJ/kg

Given that C_P of the feed = 3.75 kJ/kg-K, U_1 = 1.8 kW/m^2-K, and U_2 = 0.63 kW/m^2-K, where the BPR at the last effect is 6K,

$\Delta T_{total} = \Delta T_1 + \Delta T_2$
$\Delta T_{total} = (T_s – T_{V1}) + [T_{V1} – (T_{V2} + BPR)] = T_s – T_{V2} - BPR$
$\Delta T_{total} = 399.1275 – 330.7890 – 6$
$\Delta T_{total} = 62.3385$ K

$$\Delta T_1 = \frac{\Delta T_{TOTAL}(\frac{1}{U_1})}{\frac{1}{U_1} + \frac{1}{U_2}}$$

$$\Delta T_1 = \frac{62.3385(\frac{1}{1.8})}{\frac{1}{1.8} + \frac{1}{0.63}}$$

$\Delta T_1 = 16.1618$ K,
$\Delta T_2 = 46.1767$ K

Using the data above to solve for the temperature of the vapor space in evaporator 1:
T_{v1} = 399.1275 – 16.1618 = 382.9657 K
From Perry’s Chemical Engineers Handbook, at T= 382.9657 K, λ_v = 2230.5604 kJ/kg

Heat Balance:
Because there is no specific temperature for the liquor, it will be assumed to have the same T as with the vapor space.

For the first evaporator:
$q = FCp(T_{v1} – T_F) + V\lambda_V$
$q = 2.5(3.75)(382.9657-375) + V_1(2230.5604)$ [1]

For the second evaporator:
$q = L_1Cp(T_{v2} + BPR - T_{v1}) + V_2(\lambda_{v2} + 0.2555BPR)$
$q = (2.5 – V_1)(3.75)(330.7890 + 6 – 382.9657) + (1.8182 – V_1)[2362.7913 + 0.2555(6)]$
Since $q = V_1\ \lambda_v$
$V_1(2230.5604)= (2.5 – V_1)(3.75)(330.7890 + 6 – 382.9657) + (1.8182 – V_1)[2362.7913 + 0.2555(6)]$
V_1 = 0.8743 kg/s
V_1 = 52.4580 kg/min

22. For the area of the evaporator, use the equation [1].
$q = 2.5(3.75)(382.9657-375) +(0.8743)(2230.5604)$
q = 2024.8574 kW

$q = U_1A_1\Delta T_1$
$2024.8574 = 1.8(A_1)(16.1618)$
A_1 = 69.6040 m^2

23. For the area of the second evaporator, same equation will be used:
$2230.5674(0.8743) = 0.63(A_2)(46.1767)$
A_2 = 67.0365 m^2

24. The water flows vertically upward from the bottom of a vertical tube evaporator.
T_i = 130°F
V = 1.5 ft/s
O.D. = 2”
Δx = 0.065”
q = 284 000 BTU/hr
At the end, $x_L = x_V$

Using the data from Perry’s Chemical Engineers Handbook:
At 4 psi_a, T_o = 152.8062°F
Q = vA
$Q = 1.5(\frac{(2"/2 - 0.065)^2}{12})\pi$
Q = 0.0286 ft^3/s
m = Qρ
m = 1.7855 lb/s

For the energy associated with the flow of water along the tube,
$\Delta H_1 = Cp\Delta T$
Δ H = 1(152.9062 – 130)
Δ H = 22.8062 BTU/lb

For the energy absorbed by the water,
$\Delta H = 284\ 000/[(1.7855)(3600)]$
$\Delta\ H = 44.1831$ BTU/lb

If 1 lb of water flowing through the tube is vaporized, it will need 969.8251 BTU amount of energy. This is referred to the latent heat of vaporization of water at standard condition. Expressed in energy, the water flowing dissipated 22.8062 BTU amount of energy but consumed 44.1831 BTU. Thus, the total energy became lower.

Assuming that 1 lb of water flows through it,
$x_{vaporized} = (44.1831 – 22.8062)/969.8251$
$x_{vaporized} = 0.0220$

If no energy dissipation will be encountered, it will still need around 920 BTU to fully vaporize.

25.

4. Filtration

5. Diffusion

3.
$N_A = 4 \times 10^{-7}$ mol/cm^2-s
$N_B = 8 \times 10^{-7}$ mol/cm^2-s
$X_A = 0.015$
T = 298 K
P = 1 atm
μ (bulk velocity) = $(N_B-N_A)/C_AX_A$ where $C_A = P/RT$
μ = [8.3145(298)][8 x 10^{-7} - 4 x 10^{-7}]/[0.015(101325)](100^3)
μ = 0.6521 cm/s

23.
$D_{AB(volumetric)} = 0.934$ ft^2/s
T = 30°C
P = 2 atm
$D_{AB} = D_{AB(volumetric)}(P/RT)$
D_{AB} = [0.934(2)(14.7)(144)]/[10.73(144)(30+273.15)(1.8)]
$D_{AB} = 4.6899 \times 10^{-3}$ lbmole/ft-hr

24. Using Chen and Othmer's equation:
At T = 0°C, 1 atm: $D_V = 0.299$ ft^2/hr
$D_{V(22°C,\ 1\ atm)} = D_V(Tf/Ti)^{1.81}(Pi/Pf)$
$D_{V(22°C,\ 1\ atm)} = 0.299(295.15/273.15)^{1.81}(1/1)$
$D_{V(22°C,\ 1\ atm)} = 0.3440$ ft^2/hr
$D_{V(22°C,\ 1\ atm)} = 0.0888$ cm^2/s

25. The system is an Ethyl Alcohol – Water solution.
T = 18°C
C = 0.12 g/cm^3
x = 0.15 cm
$D_{AB} = 1 \times 10^{-5}$ cm^2/s
A = 100 ft^2
$N_A/A = dC_A(D_{AB})/\Delta x$
$N_A = 100(0.3048)^2(100)^2(0.12)(2.205)(1\times10^{-5})(3600)/[(1000)0.15]$
$N_A = 5.8997$ lbm

26. Using Chen and Othmer's equation:
T = 25°C; T' = 80°C
P = 1 atm
$D_{AB} = 0.135$ cm^2/s
$D_{AB\ (1\ atm,\ 273.15\ K)} = (T/273.15)^{1.81}(1/P)$
$D_{AB\ (1\ atm,\ 273.15\ K)} = 0.135(1)/(298.15/273.15)^{1.81}$
$D_{AB\ (1\ atm,\ 273.15\ K)} = 0.1152$ cm^2/s
$D_{AB\ (1\ atm,\ 80°C)} = [(80 + 273.15)/273.15]^{1.81}(1/1)(0.1152)$
$D_{AB\ (1\ atm,\ 80°C)} = 0.1834$ cm^2/s

27. Using the value of D_{AB} in no. 26, $D_{AB} = 0.1834$ cm^2/s, conversion yields to:
$D_{AB} = 0.1593$ ft^2/hr

28.

29.
D = 2 cm
T = 298 K
L = 100 cm
C_{A1} = 0.125 mole/cm^3
C_{A2} = 0.051 mole/cm^3

Using the value from Geankoplis:
D_{AB} = 1.26 x 10^{-5} cm^2/s
N_A = D_{AB}(A)(dC_A)/dZ
N_A = 1.26 x 10^{-5}(π)(4/4)(0.125-0.051)/100
N_A = 2.9292 x 10^{-8} cm^2/s

31.
r = 2 mm
T = 318 K
P = 1 atm
D_{AB} = 6.92 x 10^{-6} m^2/s
P_{VAP} = 0.555 mm Hg

$$\frac{N_A}{4\pi}\left(\frac{1}{r1} - \frac{1}{r2}\right) = \frac{D_{AB}}{RT} ln \frac{P-P2}{P-P1}$$
$N_A/4π$ = {[6.92 x 10^{-6}(101325)]/[8.3145(318)]}{ln(1-0.555/760)}
$N_A/4π$ = 9.6865 x 10^{-5} mole/s

32.
kG = 3.25 x 10^{-5} kmole/s-m^2-mole fraction
T = 300 K
P = 2 atm
y_{a1} = 0.26
y_{a2} = 0.01
kG' = kGy_{BM}
kG' = 3.25 x 10^{-5}[(1-0.26)-(1-0.01)]/ln[(1-0.26)/(1-0.01)]
kG' = 2.7914 x 10^{-5} kmole/m^2-s-mole fraction

33. Using the value from no. 32:
kG'$_{\text{(in English Units)}}$ = 2.7914 x 10^{-5}(2.205)(0.3048)^2(3600)
kG'$_{\text{(in English Units)}}$ = 0.020585 lbmole/hr-ft^2-atm

34. The theory that will be applied is Penetration Theory.
MTC = $\sqrt{\frac{D_{AB}}{\pi t}}$
With this, expression becomes, MTC α 1/$\sqrt{t}$
Thus, the new MTC' = MTC(1/$\sqrt{t'}$) as referred from the problem with time being tripled.
MTC' = MTC(1/$\sqrt{3}$)
MTC' = 0.57735 MTC

35.

6. Distillation

7. Gas Absorption

12. The process is a one-stage contact process. This recovers 75% of the feed.
$y_1 = 0.25$
Converting it into a Dry Basis:
$Y = 0.25/(1-0.25) = 0.33333333$
By balance, the unreacted species will be 1-0.75 = 0.25
Unreacted solute/solvent = 0.25(0.333333) = 0.08333333
By converting to wet basis to account the number of moles of each species:
$y_2 = 0.0833333/(1+0.0833333)$
$y_2 = 0.0769$

13. Using the equation of Penetration Theory:

$$MTC = \sqrt{\frac{D_{AB}}{\pi t}}$$

MTC α $\sqrt{\frac{D_{AB}}{t}}$ If diffusivity is doubled and time is halved,

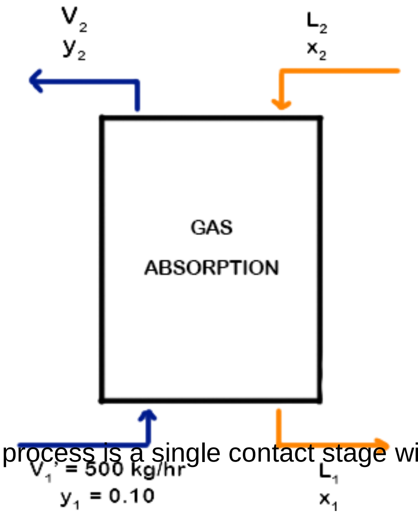
$$MTC/MTC_o = \sqrt{\frac{2D_{AB}}{(1/2)t}} \div \sqrt{\frac{D_{AB}}{t}} = \sqrt{4}$$

$MTC = 2(MTC_O)$

16.
kxa = 60 mole/hr-ft^3-mole fraction
kya = 15 mole/hr-ft^3-mole fraction
$x^* = 0.3226y$
1/Kya = 1/kya + 1/mkxa
1/Kya = 1/15 + 1/[60(0.3226)]
Kya = 8.4509 mole/hr-ft^3-mole fraction

17. This problem requires the use of data from Perry's Chemical Engineers Handbook.
Size = 13 mm Raschig rings
H = 5 m
D = 0.55 m
From Table 14-13 of Perry's Handbook:
Bed density = 880 kg/m^3
m = Bed ρ(A)(H)
m = 880(5)(0.55)^{2}π/4
m = 1045.3650 kg

23.



The process is a single contact stage with 90% recovery.

Pvap = 228 mmHg

Because the operating line is only applicable for wet basis:
y = 0.1/1+0.1 = 0.0909090909
where y* = y = 228x/760 using Raoult's Law
Substituting yields to x = x* = 0.303030303

Balance:
V'(Y_1 – Y_2) = Lmin(X*)
500[0.1 – 0.1(0.1)] = Lmin(0.3030303/1-0.3030303)
Lmin = 103.5 kg-mole/hr

31. The tower is a 10-stage absorber.
HTU = 0.85 ft
NTU = 15
HETP(N) = NTU(HTU)
HETP = 0.85(015)/10
HETP = 1.275 ft

39.
y = 0.05
mOL = 1.3
y* = 0.8x
Y_1 = 0.08
Y_2 = 0.03
X_2 = 0
MTC: kxa = 60; kya = 15
To find the interfacial concentration yi,

$$\frac{y-yi}{x-xi} = \frac{-kxa}{kya}$$

Because x can be found along the Operating Line only at Wet Basis, Y = 0.05/(1-0.05) = 0.05263
Using the Balance: V'(Y_1 – Y_2) = L'(X_1) where Y_1 would be the new interfacial mole fraction,
V'(0.05263 – 0.03) = L'(X_1)
Since V'/L' = mOL= 1.3, X_1 = (0.05263-0.03)/1.3
X_1 = 0.01741
By conversion to its dry basis:
x_1 = x = 0.01741/(1+0.01741) = 0.0171111

Substitution to the equation, where equilibrium curve is given by y* = 0.8x, or yi = 0.8xi,

$$\frac{0.05263-yi}{0.017111-yi/0.8} = -4$$

yi = 0.02018

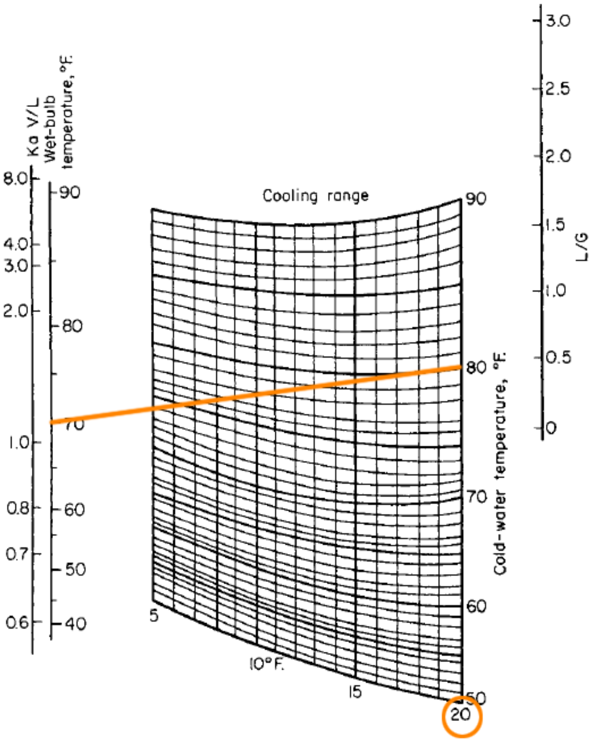
40.

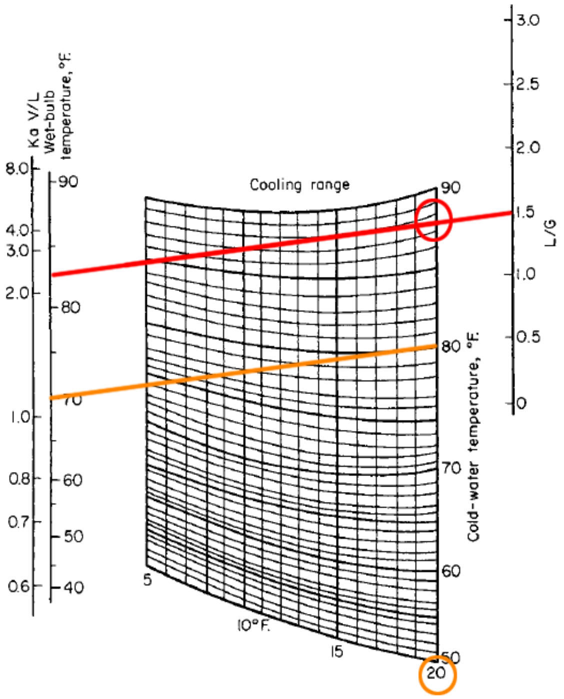
11. Relative humidity is the ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at the same temperature (Wikipedia, 2015).
$V = 1200\ ft^3/min$
RH = 20%
Tdb = 150°F

$RH = P_A/P_{Avap}$
At 150°F,
$P_{Avap} = 25896.7917$ Pa
$P_A = 0.25(25896.7917) = 5179.3583$ Pa
H = 5179.3583(18.02)/[28.97(101325-5179.3583)]
H = 0.03351 lb H_2O/lb dry air
$v_H = \frac{359(\mathrm{T,°R})}{491.67}\left(\frac{1}{MB}+\frac{H}{MA}\right)$
$v_H = \frac{359(609.67)}{491.67}\left(\frac{1}{28.97}+\frac{0.03351}{18.02}\right)$
$v_H = 16.1940\ ft^3/lbm$
$m = V/v_H$
m = 1200/16.1940
m = 74.1013 lbm/min

18. This problem utilizes Figure 12-8b of Perry's Chemical Engineers Handbook (8th Edition).
L = 7500 lb/hr
G = 5000 lb/hr
L/G = 1.5

Trange = Tdb – Twb = 90°F – 70°F = 20°F
The Tcold is connected to the Twb as intersected by the cooling range.





Then, the new Twb is determined by drawing a parallel line that intersects L/G value of 1.5 as calculated before.

By reading the new Twb from the encircled red mark, the new Twb = 88°F.

19. This problem utilizes the Figures 12-8c and 12-8d from Perry's Chemical Engineers Handbook (8th Edition).

The first line is drawn connecting Thot = 115°F and Twb = 70°F

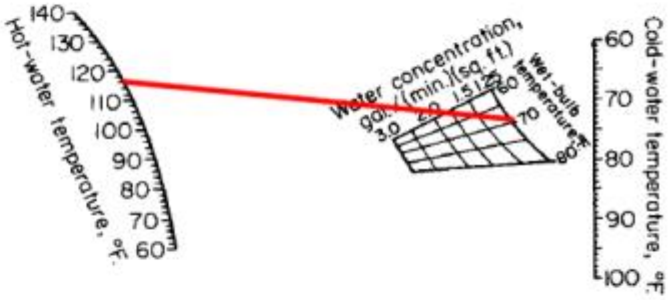
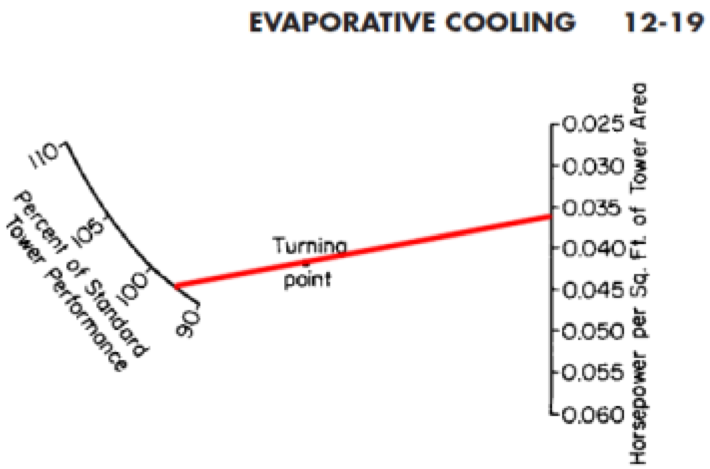


FIG. 12-8c Sizing chart for a counterflow induced-draft cooling tower. For induced-draft towers with (1) an upspray distributing system with 24 ft of fill or (2) a flume-type distributing system and 32 ft of fill. The chart will give approximations for towers of any height. (*Ecodyne Corp.*)

This intersects the point 1.8 of water concentration in gal/min-ft^2. Using the given 500 GPM, the area = 500/1.8
A = 277.7778 ft^2



Using this figure to find the power, a line is drawn from 95% performance as given, through its turning point, yielding the hp/ft^2 at 0.0357.

Fan Horsepower = 0.0357(277.7778)
Fan Horsepower = 9.9167 hp

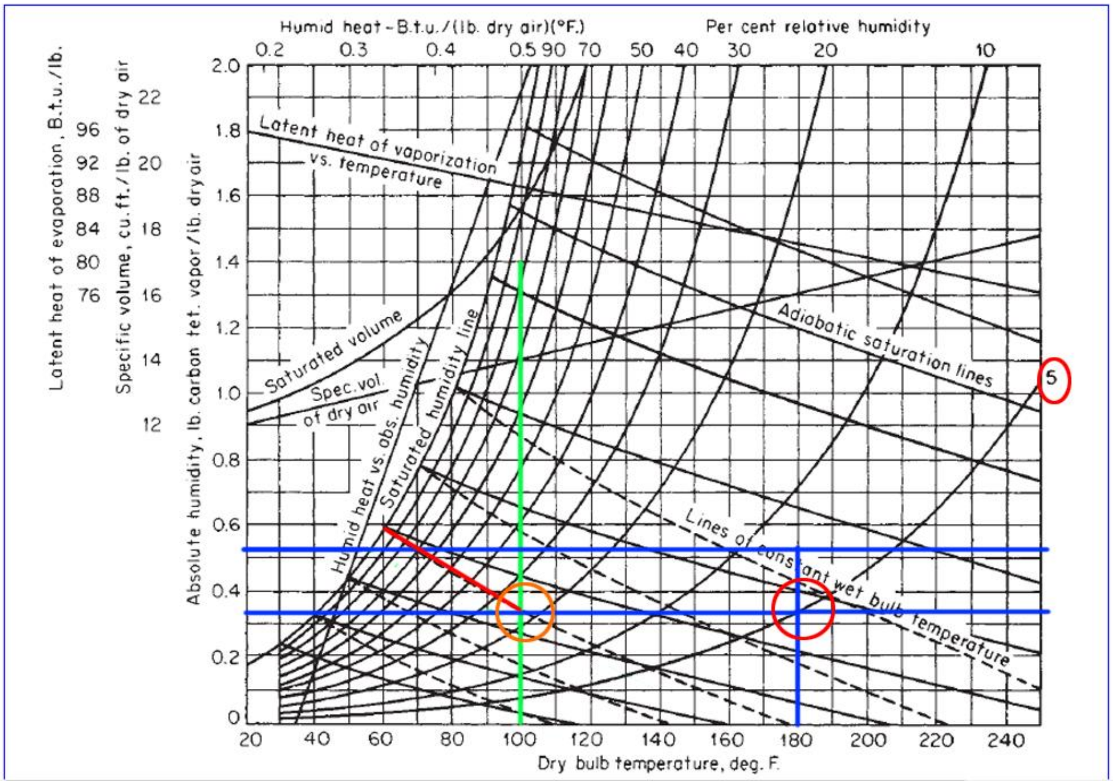
22. From Perry's Chemical Engineers Handbook, equation 12-14c:
$W_e = 0.00085W_c(T_1-T_2)$

$T_1 = 100°F$
$T_2 = 80°F$
The drift loss is 0.5%, where $W_c = 5000$ GPM

$W_e = 0.00085(5000)(100-80)$
$W_e = 85$
$W_d = 0.005(5000)$
$W_d = 25$

$W_m = W_d + W_e + W_c$ but the process does not specify the number of cycles, thus it will be assumed as 1 and $W_c = 0$.
$W_m = 25 + 85$
$W_m = 110$ GPM

23. This problem utilizes the chart from Perry's Chemical Engineers Handbook (7th Edition), Figure 12-37.



At 100°F dry bulb temperature and 60°F wet bulb temperature; the humidity is around 0.34 lb H_2O/lb dry air which is around 21% RH.

Increasing the dry bulb temperature to 180°F at constant humidity, the new RH = 5%.

24. To solve this problem using the method presented by Geankoplis, the following variables should be found, unless other assumptions shall be made:
The slope of the Operating Line;
The graph of the Equilibrium Curve and
The slope of the Tie Line

Because only two temperatures are given, the generation of the equilibrium curve will be linear.
T_1 = 100°F
T_2 = 120°F

Hy_1 = 52 BTU/lb
Hy_2 = 75 BTU/lb

From the Table 12-4 of Perry's Chemical Engineers Handbook (8th Edition), at the two temperatures, the enthalpies of saturated air can be found. These data gathered can provide us the slope of the equilibrium curve (mEC = 2.3905) and the given data can provide us the slope of the operating line (mOL = 1.15). However, there is no way that the tie line's slope can be found since it needs the value of the liquid phase heat transfer equation and the enthalpy transfer equation (i.e. –hLa/K'ya).

Thus, the final assumption that will be made is to assume that h_La >> K'ya. This provides the integral method for finding the number of transfer units from the given limits Hy, where it needs the value of Hyi approaching to Hy*. From the knowledge about Calculus that as the limits approach to a certain value, this assumes the value itself. The final equation for NTU:

$$\text{NTU} = \int_{Hy1}^{Hy2} \frac{dHy}{Hy^{*}-Hy}$$

Hy* can be found from the Table 12-4, at the interface of the mass transfer, that is simply the temperatures between the limits given.

Several interpolations are made and the generated Hy* are:

Ti = 105°F	82.035 BTU/lb
Ti_1 = 106.67°F	85.4769 BTU/lb
Ti_2 = 111°F	95.06 BTU/lb
Ti_3 = 113.34°F	101.4248 BTU/lb
Ti_4 = 115°F	105.94 BTU/lb

The values above can all be used from the equation to find NTU:
Using the two values above, NTU ~ 1.2
Using the two latter values above, NTU ~ 0.6

This problem provides us an ambiguity to what value of NTU would be reported however, general problems on finding the height of a tower indicates that Ti can be found almost at the middle of the operating line, to which narrows down the values to Ti_2 = 111°F (because this is almost at the middle of 120°F and 100°F).

Using this value:

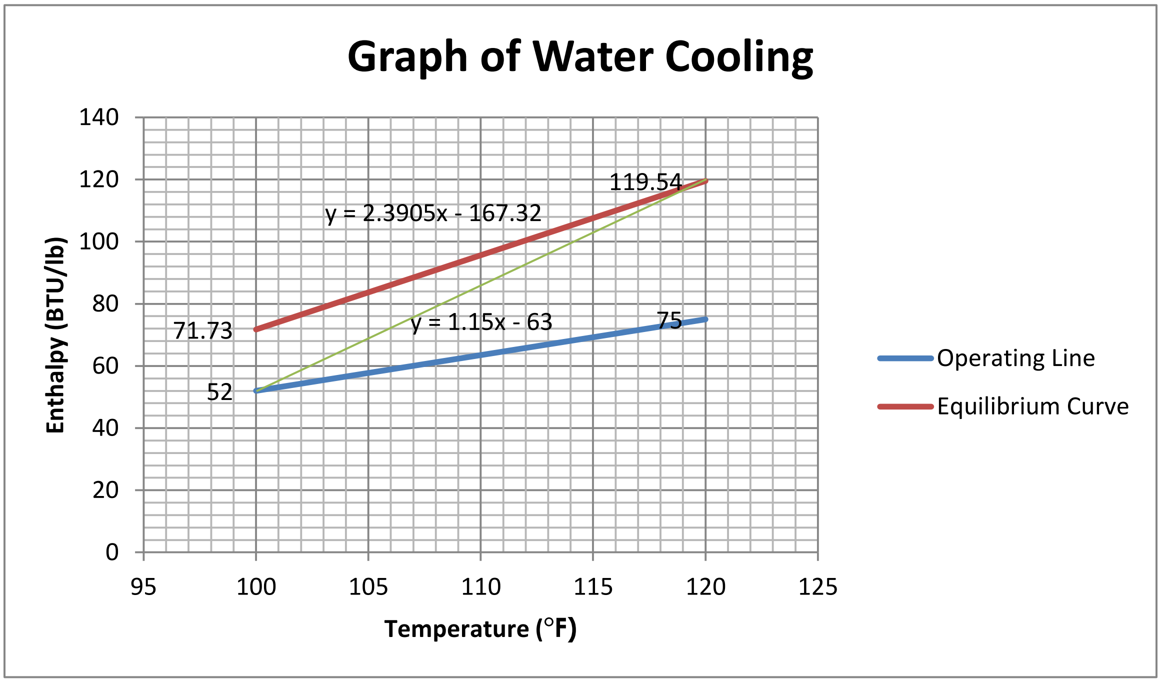
$$\text{NTU} = \int_{52}^{75} \frac{dHy}{95.06-Hy}$$

NTU = 0.7639

25. The data on problem 24 shall be used to draw the graph and find the minimum/maximum flow rate.

The equation of the Operating Line is $y = 1.15x - 63$.
This is obtained from slope $= \frac{Hy2-Hy1}{T2-T1} = \frac{75-52}{120-100} = 1.15$ where it can also be found using the calculator's statistics data by plotting T as X and Hy as Y values.

The Equilibrium Curve (Line) can be generated using Table 12-4 where Hs values shall be determined.
For 120°F, H_{s2} = 119.54 BTU/lb and for 100°F, H_{s1} = 71.73 BTU/lb
Therefore, the equation of the Equilibrium Line is $y = 2.3905x - 167.32$



The green line that connects the EC and OL has as slope of L/Gmin. The slope of this line can be determined by the points on the graph.
L/Gmin = (119.54 - 52)/(120-100) = 3.377
Thus, L can be determined from the given G = 1000 lb/hr:

L = (1000)3.377
L = 3377 lb/hr

31.
K_Ga = 230 lb H_2O/hr-ft^2-atm
By dimensional analysis, dividing it to absolute humidity in air-water system:
K_Ga = 230(29/18)
K_Ga = 370.5556 lb H_2O/hr-ft^2-atm

35. The room is 20 x 20 x 10 ft, supplied for every 5 minutes.
$V = 20(20)(10)/5 = 800\ ft^3/min$
The condition of inlet air:
$Tdb_1 = 70°F$
$Twb_1 = 65°F$
The condition of the air outside:
$Tdb_2 = 120°F$
$Twb_2 = 100\ °F$

A ton of refrigeration = 12000 BTU/hr
From the Psychometric Chart:
$H_1 = 0.012$ lb H_2O/lb dry air
$H_2 = 0.038$ lb H_2O/ lb d.a.

The humid volume based on the inlet condition:
$v_H = 359(529.67)(1/28.97 + 0.012/18.02)/491.67$
$v_H = 13.6074\ ft^3/lbm$ d.a.
where the λ at datum temperature (32°F) = 1074.9256 BTU/lb

A = 800/13.6074 = 58.7914 lbm d.a./min

The specific heat capacities are given by the equation $c_s = 0.24 + 0.46H$
$c_{s1} = 0.24 + 0.46(0.012) = 0.24552$ BTU/lb°F
$c_{s2} = 0.24 + 0.46(0.038) = 0.25748$ BTU/lb°F
$c_{save} = 0.2515$ BTU/lb°F

$W = A(H_2-H_1)$
$W = 58.7914(0.012-0.038)$
$W = 1.5286$ lb H_2O/min

$q = Ac_{save}(Tdb_2 – Tdb_1) + W\lambda$
$q = 58.7914(0.2515)(120-70) + 1.5286(1074.9256)$
q = 2382.43307 BTU/min
q = 142945.9842 BTU/hr

ton of refrigeration = 142945.9842/12000
ton of refrigeration = 11.9122

36.
$m_1 = 100$ lb dry air
Tdb = 50°F
Twb = 50°F

$m_2 = 300$ lb dry air
Tdb = 110°F
Twb = 80°F

For the easiest way of calculation, refer at Table 12-4 for direct values.
At condition 1: $m_1 = 100$ lb of dry air
$H_S = 7.658 \times 10^{-3}$ lb H_2O/lb d.a.
$c_{s1} = 0.24 + 0.46(7.658 \times 10^{-3}) = 0.2435$ BTU/lbm-°F

At condition 2, using psychometric chart for 300 lb of dry air:
$H_2 = 0.015$ lb H_2O/lb d.a.
$c_{s2} = 0.24 + 0.46(0.015) = 0.2469$ BTU/lbm-°F

Knowing that the heat balance is simply $q_{in} = q_{out}$,
$m_1c_{s1}\Delta T_1 = m_2c_{s2}\Delta T_2$
100(0.2435)(T-50) = 300(0.2469)(110-T)
T = 95.1555 °F

37. The wet bulb temperature can be determined by using the psychometric chart for the resulting humidity and the dry bulb temperature.

H = total H_2O/total dry air
Total Mass Balance:
$m_1H_1 + m_2H_2 = m_3H_3$
$W = m_1H_1 + m_2H_2$
$W = 300(0.015) + 100(7.658 \times 10^{-3})$
W = 5.2658 lb H_2O
H = 5.2658/400
H = 0.01316 lb H_2O/lb d.a.

From the psychometric chart at Tdb = 95.1555°F and H = 0.01316 lb H_2O/lb d.a.,
Twb = 75°F

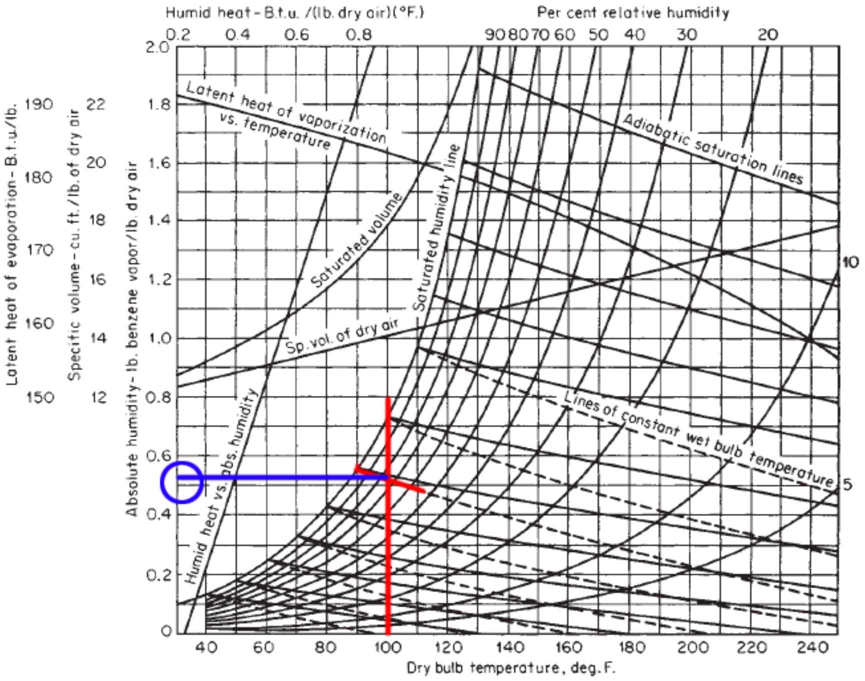
38. This problem can easily be solved using interpolation from Table 12-4 of Perry's Chemical Engineers Handbook (8th Edition):

Interpolate between 26.46 BTU/lb and 34.09 BTU/lb where x values are 60°F and 70°F respectively. The value at 30 BTU/lb is x = 64.6°F.

Why does the obtained value almost equal to the final answer? Interfacial temperature is dependent on the enthalpy evaluated between the final and initial temperature. Since the values on Table 12-4 are the values for the equilibrium curve, it can be solved directly because interfacial values lie on the equilibrium curve itself.

39. Using Mickley's Method:
dHy/dTy = (Hyi – Hy)/(Tyi-Ty)
dHy/dTy is determined using the previous values as solved from no. 24.
dHy = 95.06 – 52 = 43.06
dTy = 111 – 100 = 11
dHy/dTy = 3.9145
Using this slope to find the outlet air temperature via the same interfacial enthalpy,
3.9145 = (95.06 – 71.73)/(Tyi – 100)
Tyi = Toutlet = 105.9599°F

40. Using the Psychometric Chart from Perry's Chemical Engineers Handbook (7th Edition):



Thus,
H = 0.52 lb H_2O/lb d.a.

9. Drying

6. The moisture content on a dry basis is 120%.
Moisture_{wb} = 1.2(100%)/(1+1.2)
Moisture_{wb} = 54.5455%

25. The process is in a constant drying condition where T = 140°F.
H_{abs} = 0.03 lb H_2O/lb d.a. unknown mass
R = $0.5\text{-}e^{-60x}$ lb H_2O/hr-ft^2

For equilibrium moisture content, the rate = 0 since drying could not continue any further.
$0 = 0.5 - e^{-60x}$
x = 0.01155

26. Mass transfer coefficients (k'g) for drying can be obtained by dividing the constant rate by the difference between the saturation humidity and absolute humidity at certain temperature.
k'g = $R_c/(H_s\text{-}H)$
At T = 140°F, H_s = 0.1534 lb H_2O/lb d.a. where H = 0.03 lb H_2O/lb d.a. as given.
However, there is no equilibrium moisture content that can be used to generate the R_C.

29. It takes 6 hours to dry from 45% to 10% moisture.
X_c = 0.15
X_e = 0.03
$X_{f'}$ = 0.15

t = $\frac{Q}{ARc}\left[X_1 - X_c + (X_c - X_e)ln\frac{X_c - X_e}{X_2 - X_e}\right]$
6 = Q/AR_c[(0.45-0.15) + (0.15-0.03)ln|(0.15-0.03)/(0.10-0.03)|]
Q/AR_c = 6/(0.3646796)
Q/R_c = 16.4528 hrs

t' = 16.4528[(0.45-0.15) + (0.15-0.03)ln[(0.15-0.03)/(0.1115-0.03)]
t' = 4.9358 hrs

30. It takes 5 hours to dry from 36% to 8%.
X_i = 36%
X_f = 8%
X_c = 14%
X_e = 4%
X_i' = 8%
X_f' = 5.5%

5 = Q/AR_c[(0.36-0.14) + (0.14-0.04)ln(0.14-0.04)/(0.08-0.04)]
Q/AR_c = 16.04472 hrs
t' = 16.04472[(0.36-0.14) + (0.14-0.04)ln(0.14-0.04)/(0.055-0.04)]
t' = 6.5737 hrs

Thus, the time elapsed to dry from 8% to 5.5% = t' - t
T = 6.5737 – 5
T = 1.5737 hrs

31. It takes 5 hours to dry from 40% to 10% moisture.
X_e = 7%
X_c = 20%
X_i' = 15% (free)
X_f' = 5% (free)

$5 = Q/AR_c[(0.40-0.20) + (0.20-0.07)\ln(0.20-0.07)/(0.10-0.07)]$
$Q/AR_c = 12.8000$
Take note that in this problem, the new initial and final moisture contents given are the free moisture contents. Free moisture is the final moisture added with the equilibrium moisture. Thus:
$X_i' = 15\% + 7\% = 22\%$
$X_f' = 5\% + 7\% = 12\%$
$t' = 12.8[(0.22-0.20) + (0.20-0.07)\ln(0.20-0.07)/(0.12-0.07)]$
$t' = 1.8460$ hrs

33. The problem is a constant drying rate.
$R_c = 20$ lb/hr
$m_i = 400$ lb dry solid, with 300 lb of water
$X_c = 0.50$ (free)
$X_e = 0.050$
$X_f = 5\%$ wet basis

By converting to dry basis, $X_f = 0.05263$ and $X_c = 0.50 + 0.05 = 0.55$
$t = Q/AR_c[(X_i-X_c) + (X_c-X_e)\ln(X_c-X_e)/(X_c-X_e)]$
$X_i = 300/400 = 0.75$
Area is assumed to be 1 ft^2
$t = 400/(20)[(0.75-0.55) + (0.55-0.05)\ln(0.55-0.05)/(0.05263-0.05)]$
$t = 56.4762$ hrs

34. This problem is a simple mass balance where water is evaporated using a drier. Feed (F) enters a drier while (E) leaves as a vapor. The feed is concentrated (C) with its new moisture content.

F = 70% wt H_2O 0.70 wt H_2O/total wt of extract
E = 3.8 kg/s
C = 0.01 kg H_2O/(kg extract)
Total Mass Balance:
F = E + C
Water Balance:
0.70F = 3.8 + C(0.01)
Solving the above equations,
F = 5.4522 kg/s
The capacity is determined by the amount of coffee extract fed to the drier, thus F = Capacity.
Capacity = 5.4522(2.205)(3600)
Capacity = 43279.3255 kg/s

35. This problem is another mass balance problem.

Let E = amount of water evaporated and C = concentrated feed
F = 2000 kg/hr
$X_i = 110\%$ DB
$X_f = 5\%$ WB
Total Mass Balance:
2000 = E + C
Water Balance:
$2000[1.1/(1.1+1)] = E + 0.05C$
Solving the above equations,
E = 997.4937 kg/hr

39.
F = 1000 kg/hr
Moisture = 30% d.b.
Capacity of conveyor: 50 kg/bone dry solid-m of drier
Total drying time = 5.3 hours

Total feed = 1000(5.3) = 5300 kg
Converting the moisture content to WB: 0.3/1.3 = 0.23077
H_2O = 0.23077(5300) = 1223.0769 kg
Total bone dry solid = 5300 – 1223.0769 = 4076.9231 kg
Length = 4076.9231/50
Length = 81.5385 m

40. This problem also involves a mass balance with the use of psychometric chart.

F = 10 lb H_2O/hr
At condition 1:
T = 80°F, 25% Humidity
$H_A = H/H_s$
For saturated humidity, use Table 12-4 at T = 80°F,
$H_S = 2.233 \times 10^{-2}$ lb H_2O/lb d.a.
$H_1 = 0.25(2.233 \times 10^{-2}) = 5.5825 \times 10^{-3}$ lb H_2O/lb d.a.
$v_H = 359(539.67)/491.67[1/28.97 + 5.5825 \times 10^{-3}/18.02]$
$v_H = 13.7241$ ft^3/lbm

At condition 2:
T = 170°F
55% RH
At 170°F, P = 5.9953(0.55) = 3.2974 psi
$H_2 = 3.2974(18.02)/[(14.7-3.2974)(28.97)]$
$H_2 = 0.1799$ lb H_2O/lb d.a.

Air = $F/(H_2 – H_1)$
Air = $10/(0.1799-5.5825 \times 10^{-3})$
Air = 57.3744 lb/hr
Air = 57.3744(13.7241)/60
Air = 13.1235 ft^3/min

10. Leaching (Solid-Liquid Extraction)

11. Liquid-Liquid Extraction

12. Crystallization

4. For saturated solution of $CaCl_2 \cdot 6H_2O$ at 20°C, 6.7 gmol anhydrous $CaCl_2$ is needed per kg of water.

Saturated solution: 6.7(110.98)/[(6.7)(110.98) + 1000]
Xsat'd = 0.4265
By gravimetric method for the X kg of crystal:
$CaCl_2$ = 110.98X/219.1
H_2O = 108.12X/219.1
For 100 kg of water to form a saturated solution,

$$0.4265 = \frac{110.98X/219.1}{X+100}$$

X = 532.9471 kg of $CaCl_2 \cdot 6H_2O$

6. At 100°C, the saturated solution has 31.2% Na_2CO_3.
Na_2CO_3 = 105.99 g/mol
$Na_2CO_3 \cdot 10H_2O$ = 286.19 g/mol (dropped crystal)
$Na_2CO_3 \cdot H_2O$ = 124.01 g/mol (precipitated solid)
Xsat'd = 31.2/(100) = 0.312
Let X = the amount of $Na_2CO_3 \cdot 10H_2O$ used
124.01X/286.19 = $Na_2CO_3 \cdot H_2O$ = Y
105.99Y/124.01 = Na_2CO_3
180.2X/286.19 = H_2O
Substituting, Na_2CO_3 = 0.3703X
H_2O = 0.6297X (amount of H_2O present in $Na_2CO_3 \cdot 10H_2O$)
Xsat'd = 0.312 = Y/(Y+0.6297X)
Y = 0.28554X
The amount of Na_2CO_3 recovered = 0.3703X – 0.28554X = 0.08480X
The amount of precipitate = 0.08480X(124.01/105.99) = 0.0992174X
The % recovery = the amount of $Na_2CO_3 \cdot H_2O$ recovered/$Na_2CO_3 \cdot H_2O$ in the sample
% Recovery = (0.0992174X)(100%)/(124.01X/286.19)
% Recovery = 22.8974%

8. From the given, it should be noted that the product will be evaluated after the crystallization process and not by calcination process since anhydrous sodium sulfate is needed.

Sulfate brine: $Na_2SO_4 \cdot 10H_2O$ = 322.24 g/mol
From Perry's Chemical Engineers Handbook, at T = 0°C,
X_F = 5/(100+50) = 0.04762
Na_2SO_4 = 142.04 g/mol
For 30 000 MT Na_2SO_4:
30 000(322.24/142.04)/0.95 = 71641.79104 MT $Na_2SO_4 \cdot 10H_2O$ per year
For 300 working days/year:
71641.79104/300 = 238.8060 MT/day
The amount of liquor is the combination of salt brine and H_2O:
0.04762 = (238.8060)/(238.8060 + H_2O)
Liquor = H_2O + salt brine = 5014.926 MT

10. Soda ash is sodium carbonate, Na_2CO_3. From Perry's Chemical Engineers Handbook, Table 2-122 at T=30°C:

S = 38.8 g/100 g of H_2O

11. Sal ammoniac is ammonium chloride, NH_4Cl. From Perry's Chemical Engineers Handbook, Table 2-122 at T = 70°C:

S = 60.2 g/100g of H_2O

12. Epsom salt is magnesium sulfate heptahydrate, $MgSO_4{\cdot}7H_2O$. From Perry's Chemical Engineers Handbook, Table 2-122 at T = 10°C.

S = 30.9g/100g of H_2O

13. Saltpeter is potassium nitrate, KNO_3. From Perry's Chemical Engineers Handbook Table 2-178: the heat of solution is obtained by subtracting $H_{formation(crystal)}$ to $H_{formation(liquid/aqueous)}$

$H_{solution}$ = -118.08−(-109.79)
$H_{solution}$ = -8.29 kcal/mol

14. Hydroxybenzene is phenol, C_6H_5OH. From Perry's Chemical Engineers Handbook Table 2-183, the heat of solution at infinite dilution:

H = -2605 g-cal/mol

15. From Fig. 27.4 of McCabe's Unit Operations of Chemical Engineering, saturated $MgSO_4$ at 150°F: $MgSO_4$ saturated at 150°F has concentration mass fraction = 0.3464

H = -25 BTU/lb

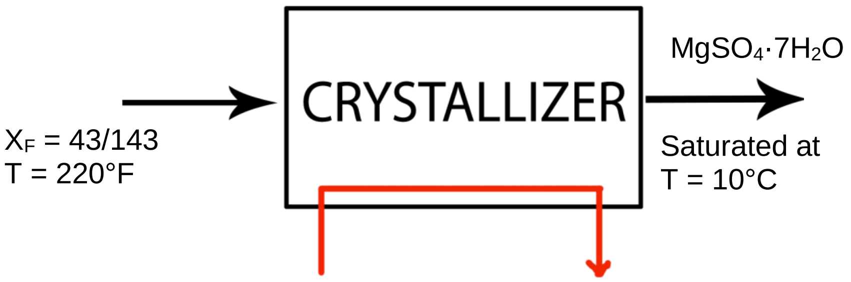
16. From Fig. 27.4 of McCabe's Unit Operations of Chemical Engineering, with 25 wt% $MgSO_4$ (x_F = 0.25) at 82.2°C (179.96°F)

H = 40 BTU/lb

17. From Fig. 27.4 of McCabe's Unit Operations of Chemical Engineering, with $MgSO_4{\cdot}7H_2O$ at 26.67°C (80.0°F)
The enthalpy can be traced from 80°F and going down through the crystal labeled.

H = -150 BTU/lb

24.



$MgSO_4$ = 120.37
$MgSO_4{\cdot}7H_2O$ = 246.51

Using an over-all mass balance:
$F = L + C$
$Fx_F = L_{XL} + C_{XC}$

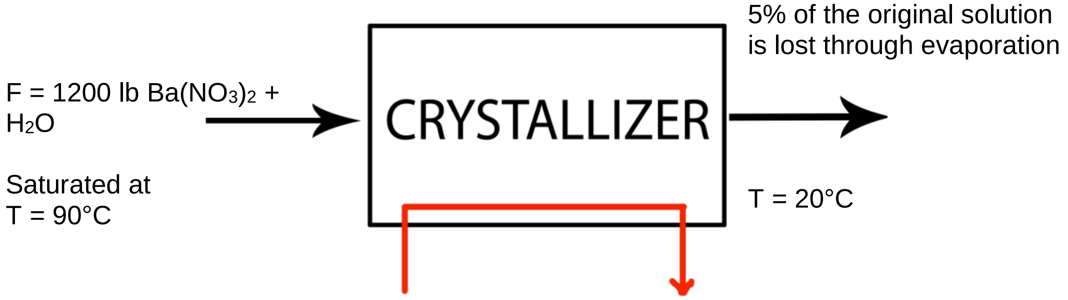
$F = L + 1$
$F(43/143) = L(30.9/130.9) + C(120.37/246.51)$

Equating the two balances:
$F = 3.9021$ lb/h

25.
At 20°C, Solubility of $NaHCO_3$ = 9.6g/100g
At 60°C, Solubility of $NaHCO_3$ = 16.4g/100g

If a saturated solution of $NaHCO_3$ at 60°C is cooled to 20°C when water = 100g,
For 60°C: 16.4 g of $NaHCO_3$
For 10°C: 9.6 g of $NaHCO_3$
During cooling, only 9.6 can be handled by the solution, the remaining 16.4-9.6 will be crystallized, thus:
%Crystal = (16.4-9.6)(100%)/16.4
%Crystal = 41.4634%

26.

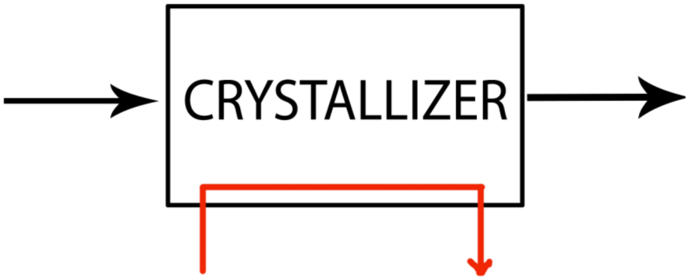


$X_F = 30.6/100 = 0.306$
$X_L = 8.6/100 = 0.086$

Balance:
$F = L + C + V$
Since V = 0.05 water on F
$0.306 = 1200/(H_2O + 1200)$
H_2O = 2721.5687 lbs
F = 3921.5686 lbs
$F = L + C + 0.05F$
$0.95F = L + C$
$0.95(3921.5686) = L + C = 3725.4902$

$FX_F = LX_L + CX_C$
Since no hydrated crystals are specified on the problem, assume that the product is anhydrous:
$X_C = 1$
$3921.5686(0.306) = L(0.086) + C$
$1200 = 0.086L + C$
Solving the two equations above:
C = 962.3718 lbs

27. Glauber's salt



$F = XNa_2SO_4 \cdot 7H_2O$
Saturated at
$T = 20°C$

$X_F = 8.4/100 = 0.084$
$P_{solution} = 1.077(1000) = 1077\ kg/m^3$
$V_{Solution} = 1L$
%Crystallized: 80%
$X_L = 19.4/119.4 = 0.162479$
$Na_2SO_4 = 142.04\ g/mol$
$Na_2SO_4 \cdot 10H_2O = 322.24\ g/mol$

Balance:
$F = L + C + V$
$F = 10^{-3}(1077) = 1.077\ kg$
$1.077 = L + C + V$

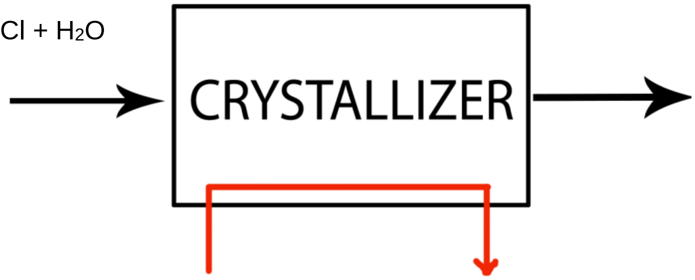
$FX_F = LX_L + CX_C$
$1.077(0.084) = L(0.162479) + C(142.04/322.24)$
$0.090468 = 0.162479L + 0.440790C$
$X_C C = 0.80(FX_F)$
$0.090468 = 0.162479L + 0.80(0.090468)$

Solving for the above equation:
$L = 0.11136\ kg$
$C = 0.164192\ kg$

$F = L + V + C$
$1.077 = 0.11136 + 0.164192 + V$
$V = 0.8014475\ kg$
$V = 801.4475\ g$

28.

$F = 1000\ kg\ KCl + H_2O$
Saturated at
$T = 363\ K$



5% of original H_2O
evaporates as water
$T = 293\ K$

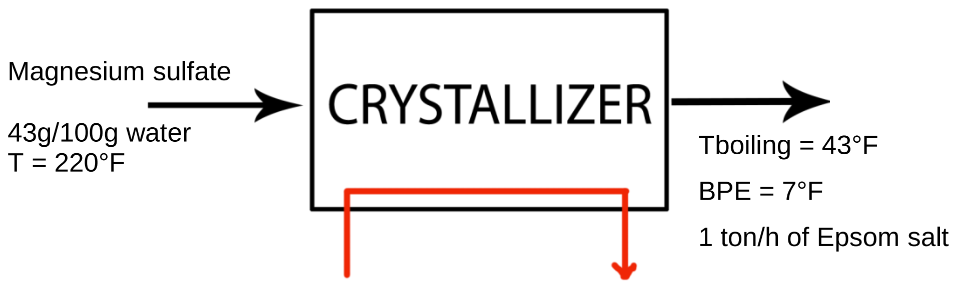
$X_F = 35/100 = 0.35$
Wt of Crystal: 5% of evaporated water
$X_L = 25.4/100 = 0.254$
KCl = 74.55 g/mol

Balance:
$F = L + C + V$
$0.35 = 1000$ kg/F
$F = 2857.1429$ kg
$V = 0.05$(original H_2O)
since KCl forms no hydrated crystals, $X_C = 1$
$2857.1429 = L + 0.05(1857.1429) + C$
$2764.2858 = L + C$

$FX_F = LX_L + CX_C$
$2857.1429(0.35) = 0.254L + C$

Solving for the above equations:
C = 399.291 kg

29.

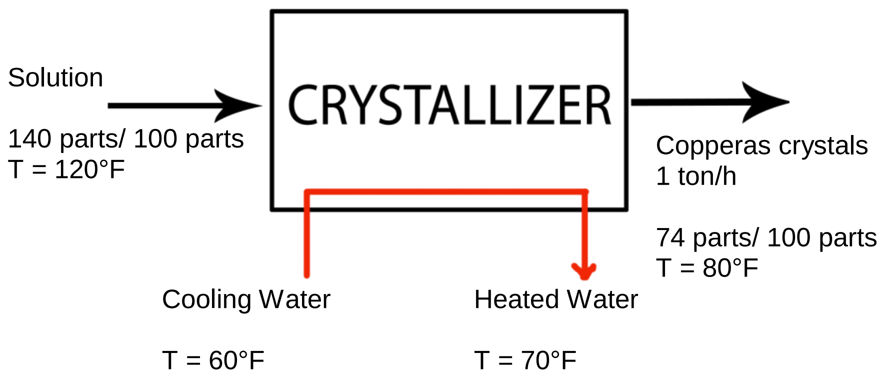


Epsom salt: $MgSO_4 \cdot 7H_2O$
$X_F = 43/143 = 0.3007$
$X_C = 120.37/246.51 = 0.48830$
From McCabe's graph:
$h_F = 50$ BTU/lb
$h_L = -50$ BTU/lb
$h_C = -165$ BTU/lb
Hv = 1079.714 (From Perry's Chemical Engineers Handbook)

C = 2205
F = L + V + 2205 lb
$Fh_F = Lh_L + VHv + Ch_C$
$F(50) = L(-50) + V(1079.714) - 165(2205)$
$F(0.3007) = 0.21L + 0.4883(2205)$

Solving for the feed using the three equations:
F = 5183.6523 lbs

30.



A/l = 3.5 ft^2 per foot of crystallizer length
l = 10 ft/unit
U = 35 BTU/h-ft^2-°F
Cp_F = 0.70 BTU/lb-°F
H_{soln} = 4400 cal/g-mole copperas
Ferrous sulfate heptahydrate (copperas) = $FeSO_4 \cdot 7H_2O$

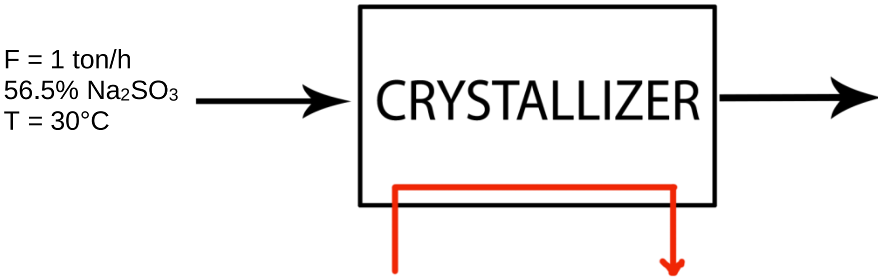
$X_F = 140/240 = 0.583333$
$X_L = 74/174 = 0.4253$
Mass Balance:
Cooling means no liquid has been vaporized. Because the copperas crystals were produced from copperas crystals itself and entered saturated, the leaving crystals would have a solubility = 1.
$F = L + C$
$F = L + 1$
$FX_F = LX_L + CX_C$
$F(0.583333) = L(0.4253) + 1$
F = 3.63657 ton = 8018.63685 lb
L = 2.63657 ton = 5813.63685 lb

Heat Balance:
$q + V\lambda_L = FCp_F(T_F - T_C) + CH_C$
Since $H_C = H_{soln}$
$q = 8018.63685(0.70)(120\text{-}80) + 2205(4400)(1/252.16)(1000/2.205)(1/278.05)$
$q = 28F + 28.4607C$
q = 287277.59 BTU/hr

Since $q_{loss} = q_{gain}$
287277.59 BTU/hr = m(1 BTU/lb-°F)(60-70)°F
m = 28727.759 lb/hr
V = 28727.759(1/60)(1/62.43)(0.3048)^3(1000) = 217.1711 L/min
V = 57.3705 GPM

31. $q = UA\Delta T_{lm}$
287277.59 BTU/h = (35 BTU/h-°F-ft^2)(3.5 ft^2/ft length)(10 ft/unit)[120-70-(80-60)/ln|(120-70)/80-60|]
287277.59 BTU/h = 40107.35755 BTU/unit-h
Units = 7.16272 ~ 7 units

32.



In this problem, evaporation (V) is negligible. The product will be sized to 14-mesh from which 20-mesh crystals were introduced.

Assuming that all crystals are in the same shape and the seed crystals are uniform in sizes in infinitesimal range:

$$\frac{dW_s}{{D_s}^3} = \frac{dW_p}{(D_s + \Delta D)^3}$$

$$dW_p = \left(\frac{D_s + \Delta D}{D_s}\right)^3 dW_s$$

$$dW_p = \left(1 + \frac{\Delta D}{D_s}\right)^3 dW_s$$

$$\int_0^{W_p} dW_p = \int_0^{W_s} \left(1 + \frac{\Delta D}{D_s}\right)^3 dW_s$$

$$W_p = \int_0^{W_s} \left(1 + \frac{\Delta D}{D_s}\right)^3 dW_s \qquad [1]$$

The mass of product crystal is related to the mass of seed crystal by the integral of the given equation above.

From Figure 18-70 of Perry's Chemical Engineers Handbook, based on visual inspection, the particle diameters are:
14-mesh: D_p = 1.19 mm
20-mesh: D_s = 0.84 mm
ΔD = 0.35 mm

Substitution to [1]:

$$W_p = \int_0^{W_s} \left(1 + \frac{0.35}{0.84}\right)^3 dW_s$$

$$W_p = 2.8432 W_s \qquad [2]$$

Balance:
F = L + C
2205 = L + C

$FX_F = LX_L + CX_C$
Since no data are given for the solubility at 30°C, Table 2-2 is utilized for the solubility at cold (20°C) and hot water (80°C). Interpolating between these values for cold water (50 parts/100 parts) and hot water (231 parts/100parts) at 30°C: X_L = 80.1667 parts/100 parts
X_L = 80.16667/(80.1667 + 100) = 0.44496

2205(0.565) = L(0.44496) + C(158.1/248.2)
1245.825 = 0.44496L + 0.63699C
Thus C = 1378.3690 lbs

$W_p = C + W_s$

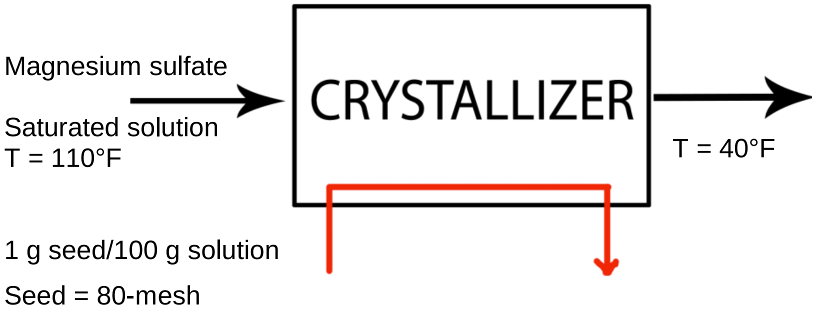
$W_p = 1378.3690 + W_s$ [3]

Solving for the mass of seed crystals using [2] and [3]:

$W_s = 747.8130$ lbs

The answer provided by MRII utilizes C = 2205 to obtain an answer ~1139 which is incorrect because it is the feed of the solution. This problem has to consider the mass balance and crystal balance on the crystallizers before equating the values of the seeds and product.

33.



For negligible evaporation and ideal crystal growth, from Figure 18-70 of Perry's Chemical Engineers Handbook by visual inspection:

80-mesh: $D_s = 0.18$ mmm

For F = 100g, $W_s = 1$ g

$W_p = \int_0^1 \left(1 + \frac{D_P - 0.18}{0.18}\right)^3 \, dW_s$

$W_p = 171.4678 D_p^3$

$W_p = W_s + C$

$171.4678 D_p^3 = 1 + C$ [1]

Balance:

From Figure 18-63 of Perry's Chemical Engineers Handbook:

$X_F = 32/100$ (110°F); $X_L = 21/100$ (40°F)

These are obtained by projecting a straight line intersecting the phase separation lines, etc.

$F = L + C$

$100 = L + C$

$FX_F = LX_L + CX_C$

$100(0.32) = L(0.21) + C(120.37/246.51)$

$32 = 0.21L + 0.4883C$

Thus, C = 39.5257 g

Substituting to [1]:

$171.4678 D_p^3 = 1 + 39.5257$

$D_p = 0.6183$ mm

By utilizing Figure 18-70 for the equivalent mesh size:

Mesh size ≈ 28

34.

A 25% wt $MgSO_4$ at 140°F is located along the phase separation, drawn from the fraction 0.25 traversing 140°F of Figure 18-63 of Perry's Chemical Engineers Handbook. This provides a solution of all the crystals of magnesium sulfate.

Cooling the solution by traversing the horizontal line backwards, it would meet the crystals of line b-c $MgSO_4 \cdot 7H_2O$ at temperature around 80°F. Tracing the line to 30°F, the fraction stops between 16.5 lb/100 lb solution to 21 lb/100 lb solution.

Thus, at T= 30°F, %Concentration = 18%

35. From the same figure, the crystals formed are $MgSO_4 \cdot 12H_2O$.

13. Sedimentation

14. Centrifugation

15. Membrane Separation

16. Flotation

17. Adsorption

18. Screening

19. Size Reduction

20. Agitation and Mixing

21. Materials Handling

22. Dimensional Analysis

3. Deriving the relations:
E = kDvρμ
ρSAE oil = 917 kg/m^3
μ = 0.29 kg/m-s

Prototype:
1/4actual mixer
½ rpm for ρalc = 789 kg/m^3; μ = 1.2 x 10^{-3} kg/m-s
A prototype shall have the same efficiency as the true equipment.

E = k(1/2)[(D actual mixer)/4](789)(1.2 x 10^{-3})
k(D actual mixer)(v)(917)(0.29) = k(1/2)[(D actual mixer)/4](789)(1.2 x 10^{-3})
v = 4.4504 x 10^{-4} rpm

5.

E. Chemical Process Industries

F1. Plant and Equipment Design

F2. Unit Operations Economics

G. Instrumentation and Process Control

16. Proportional gain is the ratio of the change in output to the change in input.
Gain = $\Delta P_{output}/\Delta T$
Gain = (15-3)/(75-71)
Gain = 12/4
Gain = 3 psi/°F

17. The proportional band (PB) is the amount of input change needed to provide a full range of output change.
PB = $\Delta T_{output}/\Delta T_{input}$
PB = (75-71)(100%)/(100-60)
PB = 10%

Note: In fact, the two problems above provoke ambiguity since Gain = 1/PB. Using this equation does not provide us the right information since the problem provides controlled variables and a certain set point.

19. This problem involves derivation of the equation:

$T(t) = T_O + 1°t/min$
Since T is the output, X = T
$X(t) = X_O + 1°t/min$ [1]
$Y(s)/X(s) = G(s)$
$Y(s) = G(s)X(s)$
Where X(s) is the Laplace transform of the varying temperature of the thermometer given by equation [1], and G(s) is the first order response by usual thermometer.

$G(s) = 1/(\tau s + 1)$
X(t) = t; where at t = 1 minute, X(t) = 1°F
$X(s) = 1/s^2$
$Y(s) = \frac{1}{\tau s+1}\left(\frac{1}{s^2}\right)$
Using partial fractions:
$Y(s) = A/(\tau s+1) + B/s + C/s^2$
By solving for the values of A, B and C:
$1 = A(s^2) + B(s)(\tau s+1) + C(\tau s+1)$
$s^2 = 0 = A + B\tau$
$s = 0 = B + C\tau$
$k = 1 = C$
$C = 1;\ B = -\tau;\ A = \tau^2$

$Y(s) = \tau^2/(\tau s+1) - \tau/s + 1/s^2$
Taking the inverse Laplace of the above equation:
$Y(t) = \tau e^{-t/\tau} - \tau + t$
$Y(t) = \tau(e^{-t/\tau} - 1) + t$

For τ = 0.2 min as given, and t = 1 min:
$Y(t) = 0.2(e^{-1/0.2} - 1) + 1$
Y(t) = 0.80134°F

The difference between the indicated temperatures:
$\Delta T = X(t) - Y(t) = 1 - 0.80134$
ΔT = 0.1987°F

21. For the system $s^3 + 3s^2 + (K+2)s + 4 = 0$ to become stable, no coefficient should contain a negative value.

This reduces the solution to K > -2. However, providing an-all positive coefficient is not enough to tell whether the system is stable or not. Thus, Routh Test must be applied.

Using Routh Test:

Row (number of terms)				
1	1 (a_o)	K + 2 (a_2)	(a_4)	
2	3 (a_1)	4 (a_3)	(a_5)	
3	(3K + 2)/3 (b_1)	0 (b_2)		
4	4 (c_1)	0 (c_2)		

$b_1 = (a_1a_2 – a_oa_3)/a_1 = [3(K + 2) – 4]/3$
$b_2 = (a_1a_4 – a_oa_5)/a_1 = 0$
$c_1 = (a_3b_1 – a_1b_2)/b_1 = [4(3K+2)/3 – 0]/ (3K+2)/3 = 4$

The system is unstable when (3K + 2)/3 < 0 and K + 2 < 0. Thus, for the system to be stable:

K < -2 (unstable)	K > -2 (stable)
K < -2/3 (unstable)	K > -2/3 ~ -0.666667 (stable)

The most appropriate value to report is when
K > -0.66667

In MRII, the only answer that suits the value of K is when K > 0.528 since it is > than – 0.6667.

25. The system has G = 2; poles at 0, -3, -1 + 2j, -1 - 2j; zeroes at -2 – j and -2 + j.
The general equation for $G(s) = K(s-r_1)(s-r_2)(s-r_n)/(s-p_1)(s-p_2)(s-p_3)(s-p_n)$

$$\mathrm{G(s)} = \frac{2[\mathrm{s} – (-2 – \mathrm{j})][\mathrm{s} – (-2 + \mathrm{j}]}{(s-0)(s+3)[(s-(-1+2j)][(s-(-1-2j)]}$$

$$\mathrm{G(s)} = \frac{2[\mathrm{s} – (-2 – \mathrm{j})][\mathrm{s} – (-2 + \mathrm{j}]}{(s-0)(s+3)[(s-(-1+2j)][(s-(-1-2j)]}$$

$$\mathrm{G(s)} = \frac{2[(\mathrm{s}+2)^2 - \mathrm{j}^2]}{(s-0)(s+3)[(s+1)^2-(2j)^2]}$$

$$\mathrm{G(s)} = \frac{2[(s^2+4s+5]}{(s)(s+3)[(s^2+2s+5]}$$

26. Amplitude ratio is obtained by substituting jw for s in the transfer function and then magnitude is taken.

$$\mathrm{AR} = |\mathrm{G(jw)}| = |\frac{1}{\sqrt{\mathrm{a}^2+\mathrm{b}^2}}|$$

G(s) = 2/(s+2)
Substituting jw to s where τ = 1:
G(jw) = 2/(jw + 2)
G(2j) = 2/(2j + 2)
G(j) = 1/(j+1)

Taking the magnitude, AR = $|1/\sqrt{1^2+1^2}|$
AR = 0.7071

27 The phase angle of this equation is derived from the G(wj) substituted function.

Phase Angle = tan^{-1}(-wτ)
Phase Angle = tan^{-1}(-1)
Phase Angle = -45°

Note: Why is w = 1 and not equal to 2? From the equation simplified, the new equation reduces to a value of w = 1 since the required equation should have a numerator of unity.

28. The function has a sinusoidal input X = 2 sin2t; G(s) = 2/[s(s+2)]

The output is represented by Y(s).
X(s) = 2(2)/(s^2 + 4)
X(s) = 4/(s^2 + 4)
Y(s) = X(s)G(s)
Y(s) = $\frac{4}{s^2+4}\ \frac{2}{s(s+2)}$ = (As + B)/(s^2 + 4) + C/s + D/(s+2)
Solving for the variables,
A = -1/2
B = -1
C = 1
D = -1/2

Y(s) = $\frac{-S}{2(s^2+4)} - \frac{2}{2(s^2+4)} + \frac{1}{S} - \frac{1}{2(s+2)}$
Y(t) = -1/2cos2t -1/2sin2t + 1 – 1/2e^{-2t}
Y(t) = -1/2(cos2t – sin2t) + 1 -1/2e^{-2t}
As t → ∞, Y(t) = -1/2(cos2t – sin2t) + 1

Notice that for this problem, a constant value still remains, proving that the G(s) is not based on a first order relation but probably a second order. However if this is a second order, the given lacks a value for the critical damping factor, thus cannot be solved.
To deal with this matter, the solution is provided on the basis that G(s) = 2/(s+2), eliminating the constant 1.

PcosA + QsinA = Rsin(A + ϕ)
R = (1/2^2 + 1/2^2)$^{-1/2}$
R = 0.70711
From the given, w = 2 and using G(s) = 2(1/2)/[(s+2)(1/2)]; G(s) = 1/(1/2s + 1) thus, τ = 1/2
Φ = tan^{-1}(-wτ)
Φ = -45°
But some argument of -45° are -225°, 765° and also angles such as -135°, -315° would give an arctangent values of -1.

Y(t) = 0.70711sin(2t - 135)

29. The transfer function is 1/(s+1)^3.

Gain margin is the amount of gain increase or decrease required to make the loop gain unity at the frequency Wgm where the phase angle is –180° (Wikipedia, 2015).

For this problem, several approaches can be used like graphical methods of Bode, Ziggler-Nichols and Nyquist. However, those methods are extremely taxing, thus the method that will be presented here is based on Tata McGraw Hill's method from the book Control Systems.

Phase frequency response: ϕ(w) = -90° - τtan^{-1}(w/c) where τ is the coefficient of s and c is the constant.

$\phi(w) = -90° - \tan^{-1}(w) - \tan^{-1}(w) - \tan^{-1}(w)$
$\phi(w) = -90° - 3\tan^{-1}(w)$
For the phase crossover frequency, the value should equal to -180° so that it can be evaluated for the gain margin.
$\phi(w_p) = -180° = -90° - 3\tan^{-1}(w_p)$
$w_p = \frac{\sqrt{3}}{3}$ rad/s

By substituting the transfer function with the complex variables jw,
$G(jw) = 1/(jw + 1)^3$
And changing to w_p for the phase crossover frequency,
$|G(jw_p)| = |1/(jw_p + 1)^3|$
$GM = 1/G(jw_p)|$
$G(jw_p) = 1/(\frac{\sqrt{3}}{3}j + 1)^3$
$G(jw_p) = |-0.64952i|$

From this point, the value that should be considered is the square root of the square of the real part and the square of the imaginary part, which in this case, is zero.
$G(jw_p) = 0.64952$

$GM = (1/0.64952)$
$GM = 1.5396$

This conforms to the value of typical GM which is around 1.6

30. The phase margin is the difference between the phase, measured in degrees, and 180°, for an amplifier's output signal (relative to its input), as a function of frequency (Wikipedia, 2015).

For the phase margin, $PM = \phi(w_G) + 180°$
To solve for w_G, the gain crossover frequency, the magnitude will be changed to unity:

$|G(jw_G)| = |1/(jw_G + 1)^3|$
$w_G = 0$

$\Phi w_G = -90° - \tan^{-1}(w_G)$
$\Phi w_G = -90° - 0°$ (or – 180)
$\Phi w_G = -90°$ (or -270°)

$PM = -90° + 180°$
$PM = 90°$ or $-90°$

32. This problem will utilize Routh Test so that the value of K will produce a stable function. The equation is $s^4 + 6s^3 + 11s^2 + 6s + K = 0$

Row (number of terms)				
1	1 (a_o)	11 (a_2)	K (a_4)	
2	6 (a_1)	6 (a_3)	(a_5)	
3	10 (b_1)	K (b_2)		
4	3(10-K)/5 (c_1)	0 (c_2)		
5	K (d_1)			

$b_1 = (a_1a_2 - a_oa_3)/a_1 = [66 - 6]/6 = 10$
$b_2 = (a_1a_4 - a_oa_5)/a_1 = (6K)/6 = K$
$c_1 = (a_3b_1 - a_1b_2)/b_1 = [6(10)-6K]/10 = 3(10-K)/5$

a_4, b_2, and d_1 all suggests that K should be greater than zero so that the system is stable.
$K > 0$

For c_1, $3(10-K)/5 > 0$
$(10-K) > 0$
$10 - K > 0$
$K < 10$

Thus, for the system to become stable: $0 < K < 10$

III. General Engineering

A. Differential Equations