BITS, PILANI-DUBAI, ACADEMIC CITY, DUBAI
Second SEMESTER 2007-2008

CHE C221 Chemical Process Calculations

Comprehensive Examination (SOLUTION)

(Closed Book)

DATE: 01-06-02008

DURATION: 3 Hours **MAXIMUM MARKS: 120**

Note: Attempt ALL questions. Draw a labeled flow diagram wherever necessary, mentioning therein all the known and unknown variables. Write all assumptions and steps clearly.

Question 1 Write brief and to-the-point answers to the following questions. Answer all the parts together and in sequence.

(a) Define selectivity and yield. [2+2]
(b) How standard atm (a unit of pressure) is related to psi and bar? [2]
(c) Differentiate between fresh feed and process feed? [2]
(d) How is specific gravity defined for liquids and for gases? [2+2]
(e) What are the assumptions made in calculating the average molecular weight of air? [2]
(f) How are absolute saturation and relative saturation related? Write the formula relating the two. [2]
(g) What is the difference between higher heating value (HHV) and lower heating value (LHV) of a fuel? [2]
(h) How mixing of real solutions differs from that of ideal solutions in terms of energy considerations? [2]

Solution: Consult class notes.

Question 2
A polymer blend is to be formed from the three compounds whose compositions and approximate formulas are listed in the table below. Determine the percentages of each compound A, B, and C to be mixed in a mixture to achieve the desired composition D. [10]

	Compound (%)			
Composition	**A**	**B**	**C**	**Desired mixture, D**
$(CH_4)_x$	25	35	55	30
$(C_2H_6)_x$	35	20	40	30
$(C_3H_8)_x$	40	45	5	40
Total	**100**	**100**	**100**	**100**

Solution:
Basis: 1 kg-mol of mixture.
Let a, b, and c be the kg-mol of each mixture; these are unknowns.
Equations:

$$0.25\ a + 0.35\ b + 0.55\ C = 0.30$$
$$0.35\ a + 0.20\ b + 0.40\ c = 0.30$$
$$0.40\ a + 0.45\ b + 0.05\ c = 0.40$$

Solving above equations simultaneously, **a = 0.60, b = 0.35, c = 0.05**.

Question 3

In a process for the manufacture of chlorine by direct oxidation of HCl with air over a catalyst to form Cl_2 and H_2O (only), the exit product is composed of HCl (4.4%), Cl_2 (19.8%), O_2 (4.0%), and N_2 (52.0%). What is

(a) the limiting reactant,

(b) the percent excess reactant,

(c) The degree of completion of reaction? [10]

Solution:

$4\ HCl + O_2 \rightarrow 2\ Cl_2 + 2\ H_2O$

Component	mol %
HCl	4.4
Cl_2	19.8
H_2O	19.8
O_2	4.0
N_2	52.0
Total	100.0

	Entering moles HCl	O_2
	4.4	4.0
2 X 19.8 = 39.6		19.8/2 = 9.9
Total	44.0	13.9

a) So, **HCl is the limiting reactant**.

b) % excess = [13.9 – (44.0/4)]/(44.0/4) * 100 = **26.36%**

c) % completion = (44 – 4.4)/44 100 = **90%**

Question 4

(a) A synthesis gas analyzing 6.4% CO_2, 0.2% O_2, 40.0% CO, and 50.8% H_2, (the balance is N_2), is burned with 40% dry excess air. What is the composition of the flue gas? [15]

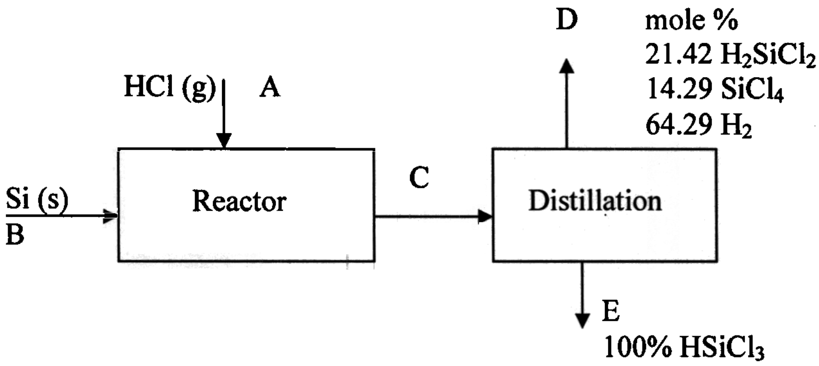
Solution:

Basis: 100 kg-mol

Comp.	%mol	reaction	reqd. O_2	CO_2	H_2O	N_2	O_2
CO_2	6.4	---	---	6.4			
O_2	0.2	----	- 0.2				
CO	40.0	$CO + ½\ O_2 \rightarrow CO_2$	20.0	40.0			
H_2	50.8	$H_2 + ½\ O_2 \rightarrow H_2O$	25.4		50.8		
N_2	2.6	---	---			2.6	
Excess O_2: (0.40)(45.2)			18.08				18.08
Total O_2 in =			63.28				
N_2 in with O_2 = (63.28)(79/21) =						238.05	
Totals				46.4	50.8	240.65	18.1

Comp.	mol	%
CO_2	46.4	13.0
H_2O	50.8	14.3
N_2	240.65	67.6
O_2	18.1	5.1
Totals	356.0	100

(b) Metallurgical-grade silicon is purified to electronic grade for use in semiconductor industry by chemically separating it from its impurities. The Si metal reacts in varying degrees with hydrogen chloride gas at 300 ^oC to form several polychlorinated silanes. Trichlorosilane is liquid at room temperature and is easily separated by fractional distillation from other gases. If 100 kg of silicon is reacted as shown in the figure below, how much trichlorosilane is produced? [15]



Solution:

Si overall mol balance: 3.560 = 0.3571 D + E (1)

Cl overall mol balance: A = D + 3 E (2)

H overall mol balance: A = 1.7142 D + E (3)

(2) & (3): 2 E = 0.7142 D

E = 0.3571 D (4)

(1) & (4): 3.56 = 0.3571 D + 0.3571 D

D = 4.9846, E = 1.7899, A = 10.3246

COMP.	**MW**
H	1.01
Si	28.09
Cl_3	<u>106.35</u>
	135.45 kg/mol

(135.45 kg $HSiCl_3$)(1.78 kg-mol)/(kg-mol $HSiCl_3$) = **241.1 kg $HSiCl_3$**

Question 5

(a) Calculate the lower heating value of methane at 100 ^oC. [10]

(b) Calculate the adiabatic flame temperature of C_3H_6 (g) at 1 atm when burned with 20% excess air and the reactants enter at 25 ^oC. [15]

Solution:

(a) CH_4 (g) + 2 O_2 (g) → CO_2 (g) + 2 H_2O (g)

Basis: 1 g-mol CH_4

$$\Delta H_{rxn}(100^o C) = \sum \Delta H_{prod} - \sum \Delta H_{react}$$

Or

$$\Delta H_{rxn}(100^o C) = \left[\left(\Delta h^o_{f,H2O}\right)\times 2 + \left(\Delta h^o_{f,CO2}\right)\times 1 + \left(\Delta h_{sensible,CO2}\right)(1) + \left(\Delta h_{sensible,H2O}\right)(2)\right]$$
$$-\left[\left(\Delta h^o_{f,CH4}\right)\times 1 + 0\times 2 + \left(\Delta h_{sensible,CH4}\right)(1) + \left(\Delta h_{sensible,O2}\right)(2)\right]$$

= **-822.66 kJ**

(b) C_3H_6 (g) + 4.5 O_2 (g) → 3 CO_2 (g) + 3 H_2O (g)

Basis: 1 g-mol C_3H_6 (g)
Air in: required O_2 = 4.5 g-mol
Excess 20% = 0.9 g-mol
Total O_2 in = 4.5 + 0.9 = 5.4 g-mol
N_2 in = 5.4 (79/21) = 20.31 g-mol

Reactants	g-mol	sens. Heat	heat-of-formation	ΔH (kJ)
C_3H_6 (g)	1.0	0	20.41	20.41
O_2 (g)	5.4	0	0	0
N_2 (g)	20.31	0	0	0
				20.41

Products: assume **T = 200 K**, consult Table D-6.

Comp.	g-mol	sens. Heat	heat-of-formation	ΔH (kJ)
CO_2 (g)	3	(92.466 – 0.912)	-393.51	-905.87
H_2O (g)	3	(73.136 - 0.837)	-241.826	-508.58
O_2 (g)	0.9	(59.914 – 0.732)	0	53.26
N_2 (g)	20.31	(56.902 – 0.728)	0	1140.89
				-220.30

Assume **T = 2500 K**

Comp.	g-mol	sens. Heat	heat-of-formation	ΔH (kJ)
CO_2 (g)	3	(123.176 – 0.912)	-393.51	-813.74
H_2O (g)	3	(98.867 – 0.837)	-241.826	-431.39
O_2 (g)	0.9	(79.119 – 0.732)	0	70.55
N_2 (g)	20.31	(75.060 – 0.728)	0	1509.68
				335.11

By linear interpolation, **T = 2180 K**.

Question 6 (a)

One thousand pounds of 10% NaOH solution at 100 ^oF is to be fortified to 30% NaOH by adding 73% NaOH at 200 ^oF. How much 73% solution must be used? How much cooling must be provided so that the final temperature will be 70 ^oF? [15]

Solution:

Basis: 100 lb of NaOH at 100 ^oF

	Conc.	lb NaOH	lb H_2O	Total
Initial	10%	100	900	1000
Added	73%	0.73 m	0.27 m	m
Final	30%	100 + 0.73 m	900 + 0.27 m	1000 + m

(100.0 + 0.73 m)/ (1000.0 + m) = 0.30
So, m = **465 lb 73% NaOH added**.

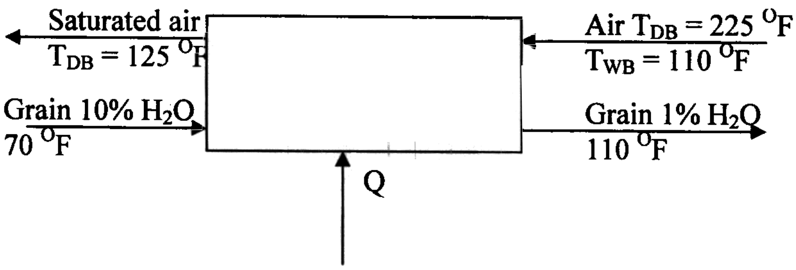
Reference state: Liquid water at 32 ^oF under its own vapor pressure (ΔH = 0 Btu/lb)
Take NaOH enthalpy values from H-x chart.
$Q = \Delta H = \Delta H_{30\%} - [\Delta H_{10\%} + \Delta H_{73\%}]$

Conc.	Temp.	lb soln.	ΔH, Btu/lb	ΔH, Btu
10	100 ^oF	1000	61	61 000
73	200 ^oF	465	371	172 600
30	70 ^oF	1465	37	54 200

Q = ΔH = (54 200) – (61 000 + 172 000) = **-179 400 Btu = Heat removed**

Question 6 (b)
A rotary drier operating at atmospheric pressure dries 2000 lb/ day of wet grain at 70 ^{O}F, from a moisture content of 10% to 1% moisture. The air flow is counter current to the flow of grain, enters at 225 ^{O}F dry-bulb and 110 ^{O}F wet-bulb temperature, and leaves at 125 ^{O}F dry-bulb as saturated. Determine:

(a) The humidity of the entering and leaving air
(b) The water removal in pounds per hour
(c) The daily product output in pounds per day [2+4+4]



Solution:

(a) The humidity of the entering air at 225 ^{O}F DB and 110 ^{O}F WB is obtained from the humidity chart as, Humidity = 0.031 lb H_2O/ lb dry air.
Exit air humidity (saturated at 125 ^{O}F) = 0.0955 lb H_2O/ lb dry air

(b) Basis: 1 hr

$$\frac{10 \text{ tons}}{\text{day}}\left|\frac{1 \text{ day}}{24 \text{ hr}}\right|\frac{2000 \text{ lb}}{} = 835 \text{ lb/hr}$$

Water in = (0.1) (835) = 83.5 lb/hr

$$\text{Water out} = \frac{(0.9)(835) \text{ lb dry grain}}{}\left|\frac{1 \text{ lb } H_2O}{99 \text{ lb dry grain}}\right. = 7.59 \text{ lb/hr}$$

Pounds H_2O removed per hr = water in – water out = 83.5 – 7.59 = 75.9 lb H_2O/hr

(c) Product output = $\left[(0.9)(835)\frac{\text{lb dry grain}}{hr} + 7.59\frac{\text{lb } H_2O}{hr}\right]\left(\frac{24 \text{ hr}}{1 \text{ day}}\right) = 18200 \text{ lb/day}$

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BITS, PILANI-DUBAI, Academic City, DUBAI

Second Semester 2007-2008

CHE UC221 Chemical Process Calculations

TEST - 2

(Open Book)

DATE: 04-05-08

DURATION: 50 MINUTES

MAXIMUM MARKS: 60

Note: Attempt ALL questions. Draw a labeled flow diagram wherever necessary, mentioning therein all the known and unknown variables. ***Text book by Himmelblau and Steam Tables are allowed.***

1 (a) At standard conditions, a gas that behaves as an ideal gas is placed in a 4.13 L container. By using a piston the pressure is increased to 31.2 psia, and the temperature is increased to 212 ^{O}F. What is the final volume occupied by the gas? [5]

1 (b) If a gas at 140 ^{O}F and 30 in. Hg abs. has a molal humidity of 0.03 mole of H_2O per mole of dry air, calculate:
(a) The percentage humidity,
(b) The relative humidity (%), and
(c) The dew point of the gas (^{O}F). [10]

2 (a) What is the enthalpy change that takes place when 3 kg of water at 101.3 kPa and 300 K are vaporized to 15 MPa and 800 K? [5]

2 (b) Two gram moles of nitrogen are heated from 50 ^{O}C to 250 ^{O}C in a cylinder. What is ΔH for the process? The heat capacity equation is:
$C_p = 27.32 + 0.6226 \times 10^{-2}\, T - 0.0950 \times 10^{-5}\, T^2$
where T is in Kelvin and C_p is in J/(g mol)(^{O}C) [5]

3 (a) Use the table of the heats of formation in Appendix F of the text book to calculate the standard heats of reaction per g-mol of the compounds produced in the following reactions: [3+3]
(a) N_2 (g) + 3 H_2 (g) → 2 NH_3 (g)
(b) Fe (s) + 1.5 Cl_2 (g) → $FeCl_3$ (s)

3 (b) The chemist for a gas company finds a gas analyses 9.2% CO_2, 0.4% C_2H_4, 20.9% CO, 15.6% H_2, 1.9% CH_4, and 52.0% N_2. What would the chemist report as the gross heating value of the gas? [9]

4 (a) The following enthalpy changes are known for reactions at 25 ^{o}C in the standard thermo-chemical state:

C_3H_6 (g) + H_2 (g) → C_3H_8 (g)	ΔH^o (kJ) = -124.0
C_3H_8 (g) + $5O_2$ (g) → $3CO_2$ (g) + $4H_2O$ (l)	ΔH^o (kJ) = -2220.0
H_2 (g) + ½ O_2 (g) → H_2O (l)	ΔH^o (kJ) = -286.0
H_2O (l) → H_2O (g)	ΔH^o (kJ) = -44.0
C + O_2 (g) → CO_2 (g)	ΔH^o (kJ) = -393.5

Calculate heat of formation of propylene. [5]

4 (b) In human body, glucose reacts as

$C_6H_{12}O_6$ (glucose) + 6 O_2 → 6 H_2O (l) + 6 CO_2 (g)

How many liters of O_2 would be required for the reaction of one gram of glucose if the conversion is 90% complete in human body? How many kJ/g of energy from glucose will be produced in the body?

Data given: Standard heat of formation (glucose) = -1260 kJ/g-mol glucose,

Assume the reaction takes place at 25 ^{o}C and 1 atm.

Assume body temperature to be 37 ^{o}C. [15]

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BITS, PILANI-DUBAI, ACADEMIC CITY, DUBAI

Second Semester 2007-2008

CHE UC221 Chemical Process Calculations

TEST - 1

(Closed Book)

DURATION: 60 MINUTES | **DATE: 23-03-08**

MAXIMUM MARKS: 75

Note: Attempt ALL questions. Draw a labeled flow diagram wherever necessary, mentioning therein all the known and unknown variables.

1 (a) A drain cleaner contains 5.00 kg of water and 5.00 kg of NaOH. What are the mass fraction and mole fraction of each component in the drain cleaner container. Given molecular weight of NaOH = 40. [1+2=3]

1 (b) Given a 50-kg gas mixture containing 10.0% H_2, 40.0% CH_4, 30.0% CO, and 20.0% CO_2. What is the average molecular weight of the gas? [3]

1 (c) How is specific gravity defined for liquids and for gases? [4]

2 Methane is burned to form CO_2 and water in a batch reactor:

$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$

The feed to the reactor and the products obtained are shown in the flow chart below.

Find out

a) How much CH_4 was consumed? What is fractional conversion of CH_4?

b) How much oxygen was consumed? What is the fractional conversion of oxygen?

c) What is the percent excess oxygen used? [3+3+4=10]

100 mol CH_4
250 mol O_2 → Reactor → 40 mol CH_4
130 mol O_2
60 mol CO_2
120 mol H_2O

3 A limestone analysis is given as

$CaCO_3$	92.89%
$MgCO_3$	5.41%
Insoluble	1.70%

Find out

a) How many kg of calcium oxide can be made from 5000 kg of this limestone?

b) How many kg of CO_2 can be recovered per kg of limestone?

c) How many kg of limestone are needed to make 1000 kg of lime? [15]

4 Antimony is obtained by heating pulverized stibnite (Sb_2S_3) with scrap iron and drawing off the molten antimony from the bottom of the reaction vessel:

$Sb_2S_3 + 3\ Fe \rightarrow 2\ Sb + 3\ FeS$

Suppose that 0.60 kg of stibnite and 0.25 kg of iron turnings are heated together to give 0.20 kg of Sb metal. Determine

a) The limiting reactant,

b) The percent of excess reactant,

c) The degree of completion (fraction),

d) The yield.

Given: molecular weights: Fe = 55.85, Sb = 121.8, S = 32.0 [3+4+4+4=15]

5 (a) A cellulose solution contains 5.2% cellulose by weight in water. How many kg of 1.2% solution are required to dilute 100 kg of 5.2% solution to 4.2%? [5]

5 (b) A cereal product containing 55% water is made at the rate of 500 kg/h. you need to dry this product so that it contains only 30% water. How much water has to be evaporated per hour? [5]

6 16 kg of methane is burned with 300 kg air. Find out the composition of flue gas in mole percent. [15]

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