BITS, PILANI-DUBAI

Dubai International Academic City, Dubai, U.A.E.

II Year Chemical Engineering, II Semester 2008-09

COMPREHENSIVE EXAM

CHE C221 Chemical Process Calculations

Maximum Marks: 80 Weightage: 40%

Duration: 3 hr (Closed Book) 20.05.2009

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.

1.(a) Define limiting reactant. (2 m)

(b) Convert 39.8 kg of NaCl per 100 kg of water to kg moles of NaCl per kg mole of water. (2 m)

(c) Gypsum is produced by the reaction of calcium carbonate and sulfuric acid. A certain lime stone analyzes: $CaCO_3$ 96.89%, $MgCO_3$ 1.41%, inerts 1.7%. For 5 tons of lime stone reacted completely, determine (6 + 6+ 4 m)

(i) kg of anhydrous gypsum ($CaSO_4$) produced

(ii) kg of sulfuric acid solution (98 wt%) required

(iii) kg of CO_2 produced

MW: $CaCO_3$ = 100.1 $MgCO_3$ = 84.32 H_2SO_4 = 98 $CaSO_4$ = 136 $MgSO_4$ = 120

$CaCO_3 + H_2SO_4 \longrightarrow CaSO_4 + H_2O + CO_2$

$MgCO_3 + H_2SO_4 \longrightarrow MgSO_4 + H_2O + CO_2$

2.(a) Define orsat analysis and stack gas. (3 m)

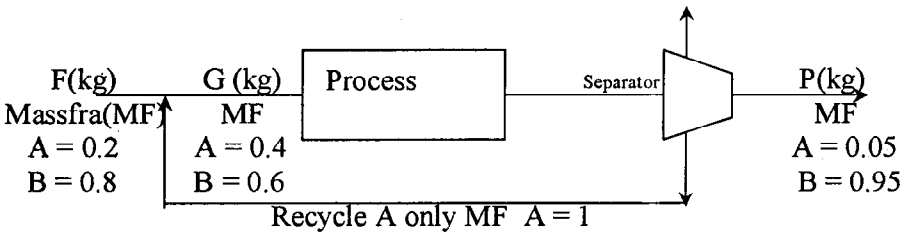
(b) Fuels for motor vehicles other than gasoline are being eyed because they generate lower level of pollutants than does gasoline. Compresses propane has been suggested as a source of economic power of vehicles. Suppose that in a test 20kg of C_3H_8 is burned with 400kg of air to produce 44 kg of CO_2 and 12 kg of CO. What is the percent excess air? (7 m)

(c) In a company two furnaces were operated. One with natural gas and other with fuel oil. In the oil furnace own supply of O_2 was made. A gas stream that analyzed O_2 20%, N_2 76%, CO_2 4% (the stack gases went up a common stack). After some years, fuel supply was stopped. The reserve of fuel oil was only 5600gal. How many hr could the oil furnace operate? How many kgmol/hr of NG were being consumed? The minimum heating load into the stack gas output was 6205 kgmol/hr of dry stack gas. Analysis of the fuels and stack is (10 m)

NG	Fuel oil	stack gas	
CH_4 96%	C 50%	N_2	84.93%
C_2H_2 2%	H_2 47%	O_2	4.13%
CO_2 2%	S 3%	CO_2	10.84%
		SO_2	0.1%

The MW of the fuel oil is 7.91 and its density is 7.578 kg/gals

(d) Based on the process drawn in the diagram, what is kg recycle/kg feed if the amount of W is 100 kg? The known compositions are inserted on the process diagram. (8 m)



3. (a) Define molal humidity. (2 m)

(b) Calculate the vapor pressure of benzene at 50°C using the Antonine equation. Also estimate the normal boiling point of benzene (the vapor pressure at 1 atm) (4 m)

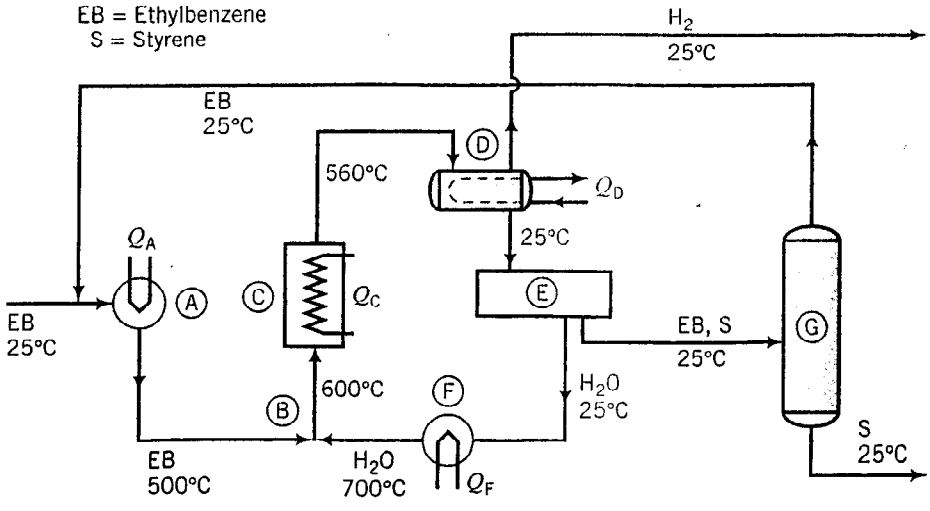
(c) The air supply for a dryer has a dry bulb temperature of 32°C and a wet bulb temperature of 25.5°C. It is heated to 90°C by coil and blown into the dryer. In the dryer, it cools along an adiabatic cooling line as it picks up moisture from the dehydrating material and leaves the dryer fully saturated. What is the dew point of the initial air and its humidity? (6 m)

4. (a) What is the significance of Hx chart? (2 m)

(b) Ethylbenzene is converted in the catalytic dehydrogenation reaction

C_8H_{10} gives $C_8H_8 + H_2$; $\Delta H°r$ (600°C) = 124.5 KJ/mol

A flowchart of simplified version of the commercial process is shown here.



Fresh and recycled liquid methylbenzene combine and are heated from 25°C to 500°C @ A, and the heated ethyl benzene is mixed adiabatically with steam at 700°C @ B to produce the feed to the reactor at 600°C. (The steam suppresses undesired side reactions and removes carbon deposited on the catalyst surface). A one through conversion of 35% is achieved in the reactor @ C, and the products emerge at 560°C. The product stream is cooled to 25°C @ D, condensing essentially all of the water, ethyl benzene, and styrene and allowing hydrogen to pass out as is coverable by-product of the process.

The water and hydrocarbon liquids are immiscible and are separated in a settling tank decanter @ E. The water is vaporized and heated @ F to produce the steam that mixes with the ethyl benzene feed to the reactor. The hydrocarbon stream leaving the decanter is fed to a distillation tower @ G (actually, a series of towers), which separates the mixture into essentially pure styrene and ethyl benzene, each at 25°C after cooling and condensation steps have been carried out. The ethyl benzene is recycled to the reactor preheater, and the styrene is taken off as a product. (12 + 4 + 2 m)

(i) Calculate on the basis of 100 kg/h styrene produced the required fresh ethyl benzene feed rate, the flow rate of recycled ethyl benzene, and the circulation rate of water, all in mol/hr (assume p = 1 atm)

(ii) Calculate the required rates of heat input or withdrawal in KJ/h for the ethylebenzene preheater @ A

(iii) Suggest possible ways to improve the energy economy of this process.

Physical property data: styrene MW = 104.15

Ethylbenzene : $(Cp)_l$ = 182 J/mol°C, ΔHv = 36 kJ/mol @ 136°C,

$(Cp)_v$ (J/mol°C) = 118 + 0.30T (°C)

Styrene ($(Cp)_l$ = 209 J/mol°C, ΔH_v = 37.1 kJ/mol @ 145°C,

$(Cp)_v$ (J/mol°C) = 115 + 0.27T (°C)

Vapor Pressures of Various Substances

Antoine equation:

$$\ln (p^*) = A - \frac{B}{C + T}$$

where p^* = vapor pressure, mm Hg
T = temperature, K
A, B, C = constants

Name	Formula	Range (K)	A	B	C
Acetic acid	$C_2H_4O_2$	290–430	16.8080	3405.57	−56.34
Acetone	C_3H_6O	241–350	16.6513	2940.46	−35.93
Ammonia	NH_3	179–261	16.9481	2132.50	−32.98
Benzene	C_6H_6	280–377	15.9008	2788.51	−52.36
Carbon disulfide	CS_2	288–342	15.9844	2690.85	−31.62
Carbon tetrachloride	CCl_4	253–374	15.8742	2808.19	−45.99
Chloroform	$CHCl_3$	260–370	15.9732	2696.79	−46.16
Cyclohexane	C_6H_{12}	280–380	15.7527	2766.63	−50.50
Ethyl acetate	$C_4H_8O_2$	260–385	16.1516	2790.50	−57.15
Ethyl alcohol	C_2H_6O	270–369	18.5242	3578.91	−50.50
Ethyl bromide	C_2H_5Br	226–333	15.9338	2511.68	−41.44
n-Heptane	C_7H_{16}	270–400	15.8737	2911.32	−56.51
n-Hexane	C_6H_{14}	245–370	15.8366	2697.55	−48.78
Methyl alcohol	CH_4O	257–364	18.5875	3626.55	−34.29
n-Pentane	C_5H_{12}	220–330	15.8333	2477.07	−39.94
Sulfur dioxide	SO_2	195–280	16.7680	2302.35	−35.97
Toluene	$C_6H_5CH_3$	280–410	16.0137	3096.52	−53.67
Water	H_2O	284–441	18.3036	3816.44	−46.13

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Dubai International Academic City, Dubai, U.A.E.

II Year Chemical Engineering, II Semester 2008-09

Test 2

CHE C221 Chemical Process Calculations

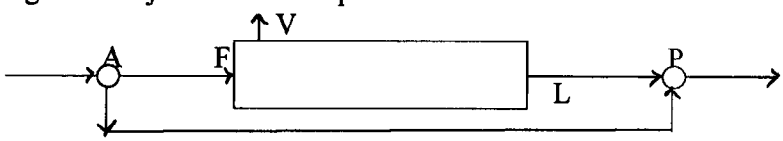
Maximum Marks: 20 Weightage: 20%

Duration: 50 min (Open Book) 30.04.2009

Note: only prescribed txt book and own handwritten notes are allowed

1. An inspector files a report against a factory owner charging the CO_2 content in the gases from chimney is well above the dangerous level of 15% (as per flue gas analysis) and against to city code. The factory owner burns the natural gas containing 100% CH_4 and 130% excess air. Is inspector's charge sustainable? (6 m)

2. Fresh orange juice contains 12% solids and rest water. It is concentrated to contain 42% solids. In the present process, the evaporator is by passed with a fraction of fresh juice. Juice that enters the evaporator is concentrated to 58% solids and is mixed with by passed juice to achieve the desired final concentration. Calculate the amount of final juice per 1000 kg of fresh juice fed to the process. (6 m)



3. A gas analyzes 60% methane and 40% ethylene by volume. It is desired to store 12.3 kg of this gas mixture in a cylinder having a capacity of $5{\cdot}14 \times 10^{-2}$ m^3 at a maximum temperature of 45°C. Calculate the pressure inside the cylinder by assuming that the mixture obeys the ideal gas laws. (4 m)

4. Calculate the standard heat of reaction without using $\Delta H°_f$ for the dehydrogenation of ethane. (2 m)

5. The corrosion of aluminum in water is normally prevented by the tightly adhering oxide layer that forms on the aluminum. If this layer were absent, as when aluminum is amalgamated with mercury in an anaerobic atmosphere, the following reaction occurs.

$$2Al(s) + 6H_2O(l) \rightarrow 2Al(OH)_3(s) + 3H_2(g)$$ (2 m)

$\Delta H°_{rxn}$ per 2 moles of Al(s) is –837.0 kJ. What is the heat of formation of $Al(OH)_{3\,(s)}$?

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II Year Chemical Engineering, II Semester 2008-09

Test 1

CHE C221 Chemical Process Calculations

Maximum Marks: 25 Weightage: 25%

Duration: 50 min (Closed Book) 22.03.2009

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

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1. Wine making involves a series of very complex reactions most of which are performed by microorganisms. The starting concentration of sugars determines the final alcohol content and sweetness of the wine. The specific gravity of the starting stock is therefore adjusted to achieve desired quality of wine. A starting stock solution has a specific gravity of 1.075 and contains 12.7 wt % sugar. If all the sugar is assumed to be $C_{12}H_{22}O_{11}$, determine g sugar/L solution. (2 marks)

2. A solvent storage tank, 15.0 m high contains liquid styrene (sp. gr. 0.909). A pressure gauge is fixed at the base of the tank to be used to determine the level of styrene.

   a. Determine the gage pressure (KPa) when the tank is full of styrene. (2 marks)

   b. If the tank is to be used for storage of liquid hexane (sp. gr. 0.659), will the same pressure gage calibration be adequate? What is the risk in using the same calibration to determine the level of hexane in the tank? (2 marks)

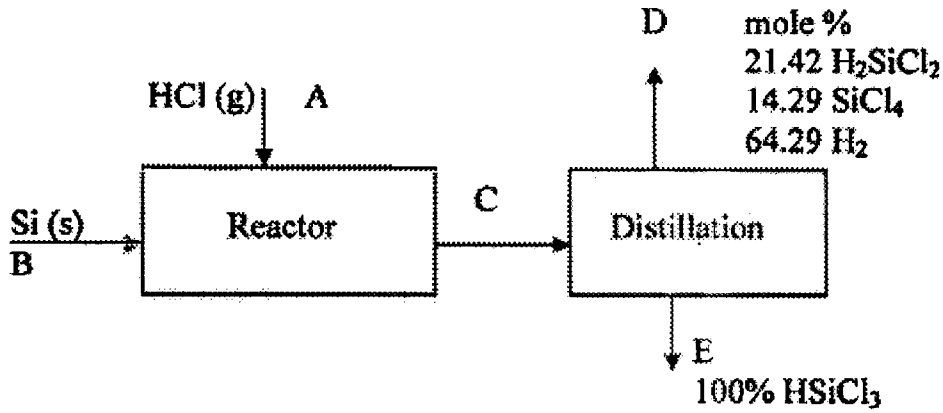
3. Two hundred kg of liquid contains 40% butane, 40% pentane, and 20% hexane. Determine the mole fraction and the mass fraction composition of the liquid on a hexane free basis. (2 marks)

4. A liquid adhesive, which is used to make laminated boards, consists of a polymer dissolved in a solvent. The amount of polymer in the solution has to be carefully controlled for this application. When the supplier of the adhesive receives an order for 3000 kg of an adhesive solution containing 13 wt % polymer, all it has on hand is (A) 500 kg of a 10 wt % solution, (B) a very large quantity of a 20 wt % solution, and (C) pure

solvent. Calculate the weight of each of the three stocks that must be blended together to fill the order. (7 marks)

5. 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°C 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? (10 marks)

(MW: Si = 28.09, Cl_3 = 10.35)



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II Year Chemical Engineering, II Semester 2008-09

QUIZ 3

CHE C221 Chemical Process Calculations

Maximum Marks: 5 Weightage: 5%

Duration: 15 min (Closed Book)

Breakfast cereal is being dried in a fluidized bed dryer in which the cereal moves counter current to the air flow. The cereal feed rate is 400 kg/hr with water content of 40%. The feed air has moisture of 2% with DB at 82°C, humidity: 0.012 kg of moisture/kg of dry air and exit air has 3% moisture (all are wt %). Determine the required inlet moist air flow rate in m^3/hr if the output cereal must have a water content of not more than 15 percent.

BITS, PILANI-DUBAI

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II Year Chemical Engineering, II Semester 2008-09

QUIZ 2

CHE C221 Chemical Process Calculations

Maximum Marks: 10 Weightage: 5%

Duration: 15 min (Closed Book)

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1. What is the specific gravity of N_2 at 80°F and 745 mmHg compared to air at 80°F and 745 mm Hg. (2 m)

2. What mass of sodium chloride (in gm) is present in 500 ml of NaCl (2 M) solution? (0.5 + 0.5 m)

3. What is called Orsat analysis? (1 m)

4. Define reduced pressure. (1 m)

5. A gaseous reaction A gives 2B + C takes place isothermally in a constant pressure reactor. Starting with a gaseous mixture containing 50% A (rest inerts), the ratio of final to initial volume is found to be 1.6. Determine the percentage conversion of A? (2.5 m)

6. A multiple effect evaporator has a capacity to process 4000 kg of solid caustic soda per day when it is concentrating from 10% to 25% solids. Calculate the water evaporated in kg. (2.5 m)

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Dubai International Academic City, Dubai, U.A.E.

II Year Chemical Engineering, II Semester 2008-09

QUIZ 2

CHE C221 Chemical Process Calculations

Maximum Marks: 10 | Answering Scheme | Weightage: 5%

Duration: 15 min | (Closed Book)

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1. What is the specific gravity of N_2 at 80°F and 745 mm Hg compared to air at 80°F and 745 mm Hg. (2 m)
   Sp gravity = 28/29 = 0.9655

2. What mass of sodium chloride (in gm) is present in 500 ml of NaCl (2 M) solution? (0.5 + 0.5 m)
   Moles = molarity x liter = 2 x 0.5 = 1 mol
   Mass of NaCl = moles x molar mass = 1 x (23 + 35.45) = 58.45 gm

3. What is called Orsat analysis? (1 m)
   All the gases resulting from combustion process not including the water vapor.

4. Define reduced pressure. (1 m)
   It is corrected or normalized conditions of pressure by their respective critical conditions.
   Pr = P/Pc

5. A gaseous reaction A gives 2B + C takes place isothermally in a constant pressure reactor. Starting with a gaseous mixture containing 50% A (rest inerts), the ratio of final to initial volume is found to be 1.6. Determine the percentage conversion of A? (2.5 m)

   Initially 1 g mole mixture containing 0.5 g mole A + 0.5 g moles (inerts) is taken.
   Finals moles are:
   (0.5-x) + 0.5 (inerts) + 2 x + x = 1+ 2x
   (1+2x)/1 = 1.6; x = 0.3 %
   Conversion of A = 0.3/0.5 = 0.6 = 60%

6. A multiple effect evaporator has a capacity to process 4000 kg of solid caustic soda per day when it is concentrating from 10% to 25% solids. Calculate the water evaporated in kg. (2.5 m)

   4000/(4000+ x) = 0.1; x = 36,000 kg/day
   4000/(4000 + x) = 0.25; x = 12,000 kg/day
   Water evaporated = 36,000 – 12,000 = 24,000 kg/day

BITS, PILANI-DUBAI, Academic City, DUBAI

Second Semester 2008-2009

CHE C221 Chemical Process Calculations

Quiz - 1 (Closed Book)

DATE: 05-03-09

DURATION: 30 MINUTES MAXIMUM MARKS: 10

Note: Attempt ALL questions. Do rough calculations on the back.

Name: I.D.:

1. 1 kg solution of 50% methanol in water is required in a lab experiment. Methanol solution available in lab is 15% methanol in water. How much pure methanol is required to be mixed in how much of available solution to get the desired solution?

Answer: Quantity of 15% methanol solution required = ...

Quantity of pure methanol required = ...

2. In a drying process moisture is reduced from 50% to 25%. Initial weight of the material is 200 kg. Calculate the final weight of the product.

Answer: Final weight of the product = ...

3. You have 25 kg of a gas of the following composition:

   CH_4 60%

   C_2H_4 30%

   C_2H_6 10%

   What is the average molecular weight of the mixture?

Answer: Average Mol. Wt. = ...

4. Butane is burned as per the following reaction:

   $C_4H_{10} + O_2 \longrightarrow CO_2 + H_2O$

   Balance the reaction.

Answer: Balanced reaction:

5. A 2.00 g sample of ammonia is mixed with 4.00 g of oxygen. Following reaction occurs:

$$4\ NH_{3(g)} + 5\ O_{2(g)} \longrightarrow 4\ NO_{(g)} + 6\ H_2O_{(g)}$$

Which is the limiting reactant?

Answer: Limiting reactant:

Tick (√) the correct option.

6. Given the reaction:

$$4\ Al_{(s)} + 3\ O_{2(g)} \longrightarrow 2\ Al_2O_{3(s)}$$

What is the minimum number of grams of oxygen gas required to produce 1.00 mole of aluminum oxide?

a) 32.0 g b) 48.0 g c) 96.0 g d) 192.0 g

7. A compound was analyzed and found to contain 75% carbon and 25% hydrogen by mass. What is the compound's empirical formula?

a) CH b) CH_2 c) CH_3 d) CH_4

8. What is the percent by mass of carbon in CO_2?

a) 12 b) 27 c) 44 d) 73

9. Given the reaction:

$$N_{2(g)} + 3\ H_{2(g)} \longrightarrow 2\ NH_{3(g)}$$

What is the total number of moles of $NH_3(g)$ produced when 10 moles of $H_2(g)$ reacts completely with $N_2(g)$?

a) 6.7 b) 2.0 c) 3.0 d) 1.5

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