Final
Question Booklet

Lakehead University
Department of Chemical Engineering
Process Control
Engineering 4152
Instructor: Leila Pakzad

STUDENT NAME:	**STUDENT No:**
STUDENT SIGNATURE:	

April. 12, 2016

9:00 a.m. – 12:00 a.m.

INSTRUCTIONS:

Closed book exam.

This examination question paper **may not** be taken from the examination room.

Please count the number of pages in this exam question paper **BEFORE** beginning to write, and report any discrepancy immediately. This is page 1 of 6 pages.

1. A gas cylinder filled with nitrogen at standard temperature and pressure has a mass of 37.289 g. The same container filled with carbon dioxide at STP has a mass of 37.440 g. When filled with an unknown gas at STP, the container mass is 37.062 g. Calculate the molecular weight of the unknown gas.

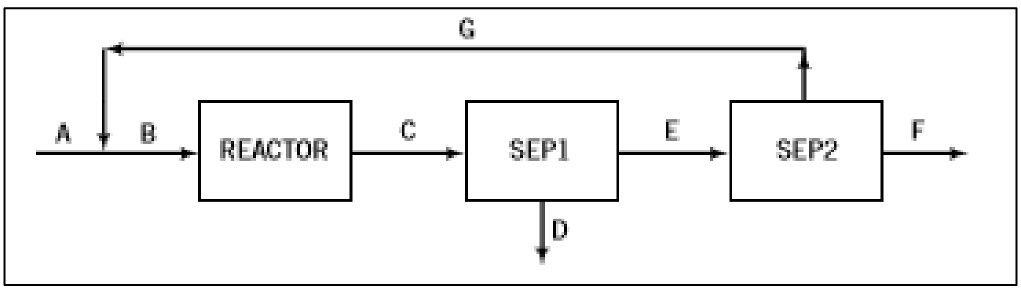
Mw of N_2: 28.02 g/gmol

Mw of CO_2: 44.1 g/gmol

Mark: 10%

****

2. A flowchart of a methanol synthesis process is shown below.



The following specifications apply to the labeled streams and process units:

A. Fresh feed-a mixture of CO, H_2, N_2, and CO_2.

B. Feed to the reactor-30.0 mole% CO, 63.0% H_2, 2.0% N_2, and 5.0% CO_2.

Reactor. Two reactions occur and proceed to equilibrium at 200°C and 4925 kPa absolute:

$$CO + 2H_2 \rightleftharpoons CH_3OH(M), \qquad (K_p)_1 = \frac{p_M}{p_{CO}p_{H_2}^2} = 3.49 \times 10^{-6}\ kPa^{-2}$$

$$CO_2 + 3H_2 \rightleftharpoons CH_3OH + H_2O \qquad (K_p)_2 = \frac{p_M p_{H_2O}}{p_{CO_2}p_{H_2}^3} = 5.19 \times 10^{-8}\ kPa^{-2}$$

C. Reactor effluent-contains all feed and product species at the reactor temperature and pressure. Species partial pressures satisfy the two given equations.

SEP1. Condense all methanol and water in reactor effluent.

D. Liquid methanol and water. (These species will be separated by distillation in a unit not shown.)

E. Gas containing N_2 and unreacted CO, H_2, and CO_2.

SEP2: Multiple-unit separation process.

F. All of the nitrogen and some of the hydrogen in Stream E.
G. Recycle stream-CO, CO_2, and 10% of the hydrogen fed to Sep2.

(a) Taking 100 kmol/h of Stream B as a basis of calculation, calculate the molar flow rates (kmol/h) and molar compositions of the labeled streams.
(b) The process is to be used to provide 237 kmol/h of methanol. Scale up the flowchart of part (a) to calculate the required fresh feed rate (SCMH), the flow rate of the reactor effluent (SCMH), and the actual volumetric flow rate of the reactor effluent (m^3/h), assuming ideal gas behavior.

$$n_i = n_{i0} + \sum_j \nu_{ij}\, \xi_j$$

$$aA + bB \rightleftharpoons cC + dD$$

$P_A = y_A . \text{P}$; $\quad\quad K_p = \frac{P_C^c . P_D^d}{P_A^a . P_B^b}$

- *Standard temperature and pressure (STP) are generally defined as 0°C and 1 atm. Standard specific volume is 22.4 L (STP)/mol or 359 ft^3(STP) /lb-mole***.**

K=°C + 273 ; PV=nRT

Mark: 30%

****

3. Methanol is contained in a large tank under a pressure of 3.1 bar absolute. When a valve on the bottom of the tank is opened, the methanol drains freely though a 1-cm ID tube whose outlet is 7.00 m below the surface of the methanol. The pressure at the outlet of the discharge pipe is 1 atm. Estimate the methanol discharge velocity and flow rate in L/min when the discharge valve is fully opened. Neglect the rate of fall of the methanol level in the tank, friction loss, and shaft work.

$$Steady - state\ Mechanical\ Energy\ Balance: \frac{\Delta P}{\rho} + \frac{\Delta u^2}{2} + g\Delta z + \hat{F} = \frac{-\dot{W}_S}{\dot{m}}$$

$\rho_{CH3OH} = 0.792 \times 10^3 \ kg/m^3$

$g = 9.81 \ m/s^2$

Mark: 15%

****

4. Answer following questions: **Mark: 15%**

(a) Name as what Methanol is used.

(b) Name the four main process steps in the production of sulfuric acid from gases containing sulfur dioxide.

(c) Draw the typical Nitric Acid production flow-chart and name the process unit operations.

(d) Write the first law of thermodynamics for a closed system (steady-state energy balance on a closed system) and define all terms involved.

(e) Write the first law of thermodynamics for an open system (steady- state energy balance on an open system) and define all terms involved.

****

5. In an absorption tower (or absorber), a gas is contacted with a liquid under conditions such that one or more species in the gas dissolve in the liquid. A stripping tower (or stripper) also involves a gas contacting a liquid, but under conditions such that one or more components of the feed liquid come out of solution and exit in the gas leaving the tower.

A process consisting of an absorption tower and a stripping tower is used to separate the components of a gas containing 30.0 mole% carbon dioxide and the balance methane. A stream of this gas is fed to the bottom of the absorber. A liquid containing 0.500 mole% dissolved CO_2 and the balance methanol is recycled from the bottom of the stripper and fed to the top of the absorber. The product gas leaving the top of the absorber contains 1.00 mole% CO_2 and essentially all of the methane fed to the unit. The CO_2 –rich liquid solvent leaving the bottom of the absorber is fed to the top of the stripper and a stream of nitrogen gas is fed to the bottom. Ninety percent of the CO_2 in the liquid feed to the stripper comes out of solution in the column, and the nitrogen/CO_2 stream leaving the column passes out to the atmosphere through a stack. The liquid stream leaving the stripping tower is the 0.500% CO_2 solution recycled to the absorber.

The absorber operates at temperature T_a and pressure P_a and the stripper operates at T_s and P_s. Methanol may be assumed to be nonvolatile—that is, none enters the vapor phase in either column—and N_2 may be assumed insoluble in methanol. **Mark: 30%**

(a) In your own words, explain the overall objective of this two-unit process and the functions of the absorber and stripper in the process.

(b) The streams fed to the tops of each tower have something in common, as do the streams fed to the bottoms of each tower. What are these commonalities and what is the probable reason for them?

(c) Taking a basis of 100 mol/h of gas fed to the absorber, draw and label a flow chart of the process. For the stripper outlet gas, label the component molar flow rates rather than the total flow rate and mole fractions.

(d) Calculate the fractional CO_2 removal in the absorber (moles absorbed/mole in gas feed) and the molar flow rate and composition of the liquid feed to the stripping tower.

(e) Calculate the molar feed rate of gas to the absorber required to produce an absorber product gas flow rate of 1000 kg/h.

Mw_{CO2} = 44 g/g-mole; Mw_{CH4}=16 g/g-mole

(f) Would you guess that T_S would be higher or lower than T_a? Explain. (*Hint*: Think about what happens when you heat a carbonated soft drink and what you want to happen in the stripper.) What about the relationship of P_s to P_a?

(g) What properties of methanol would you guess make it the solvent of choice for this process? (In more general terms, what would you look for when choosing a solvent for an absorption– stripping process to separate one gas from another?)

FACTORS FOR UNIT CONVERSIONS

Quantity	Equivalent Values
Mass	1 kg = 1000 g = 0.001 metric ton = 2.20462 lb_m = 35.27392 oz 1 lb_m = 16 oz = 5×10^{-4} ton = 453.593 g = 0.453593 kg
Length	1 m = 100 cm = 1000 mm = 10^6 microns (μm) = 10^{10} angstroms (Å) = 39.37 in. = 3.2808 ft = 1.0936 yd = 0.0006214 mile 1 ft = 12 in. = 1/3 yd = 0.3048 m = 30.48 cm
Volume	1 m^3 = 1000 L = 10^6 cm^3 = 10^6 mL = 35.3145 ft^3 = 220.83 imperial gallons = 264.17 gal = 1056.68 qt 1 ft^3 = 1728 $in.^3$ = 7.4805 gal = 0.028317 m^3 = 28.317 L = 28,317 cm^3
Force	1 N = 1 kg·m/s^2 = 10^5 dynes = 10^5 g·cm/s^2 = 0.22481 lb_f 1 lb_f = 32.174 lb_m·ft/s^2 = 4.4482 N = 4.4482×10^5 dynes
Pressure	1 atm = 1.01325×10^5 N/m^2 (Pa) = 101.325 kPa = 1.01325 bar = 1.01325×10^6 dynes/cm^2 = 760 mm Hg at 0°C (torr) = 10.333 m H_2O at 4°C = 14.696 lb_f/$in.^2$ (psi) = 33.9 ft H_2O at 4°C = 29.921 in. Hg at 0°C
Energy	1 J = 1 N·m = 10^7 ergs = 10^7 dyne·cm = 2.778×10^{-7} kW·h = 0.23901 cal = 0.7376 ft-lb_f = 9.486×10^{-4} Btu
Power	1 W = 1 J/s = 0.23901 cal/s = 0.7376 ft·lb_f/s = 9.486×10^{-4} Btu/s = 1.341×10^{-3} hp

Example: The factor to convert grams to lb_m is $\left(\frac{2.20462\ lb_m}{1000\ g}\right)$.

THE GAS CONSTANT

8.314 m^3·Pa/(mol·K)
0.08314 L·bar/(mol·K)
0.08206 L·atm/(mol·K)
62.36 L·mm Hg/(mol·K)
0.7302 ft^3·atm/(lb-mole·°R)
10.73 ft^3·psia/(lb-mole·°R)

8.314 J/(mol·K)
1.987 cal/(mol·K)
1.987 Btu/(lb-mole·°R)