ChE 101 – Final Exam
Winter 2008

Instructor: Sumit Kundu — Thursday April 10,2008

2.5 hours (12:30 – 3:00) — Location: RCH 301

Chemical Periodic Table is allowed. 2 page cheat sheet is allowed.

YOU **CAN NOT** USE A GRAPHING CALCULATOR TO SIMULTANEOUSLY SOLVE MULTIPLE EQUATIONS (but feel free to check your work with them)

PLAGIARISM/CHEATING: A zero-tolerance policy will be adhered to. No talking or sharing of Notes during the mid-term. All of the University of Waterloo mid-term and exam regulations do apply.

The question pages must be returned with the answer booklet. NUMBER ANY ADDITION PAGES ADDED and indicate the total number of pages.

HINT –NOT all questions are of equal difficulty, complexity or length. Marks for each question are not representative of the question difficulty.

Data:

Pressure: 1.0 atm = 101.3 kPa = 760 mmHg = 760 torr = 14.696 psia

Temperature: Water freezes at 0^oC = 273.15 K = 32^oF = 492^oR; boils at 100^oC = 212^oF

Quantities: Molar volume of ideal gas = 22.414 L mol^{-1} at 273.15 K and 1.0 atm. (STP)

Molecular weight of air = 29 g mol^{-1}

1 m = 3.28 ft; 2.54 cm = 1 in; 1 acre = 43,560 ft^2

28.32 L = 1.0 ft^3 1 L = 1000 cm^3

1.0 pound = 454 grams 1 cal = 4.184 J

1 erg = 1 g cm^2 s^{-2} 1 J = 1 N m 1 W = J s^{-1} 1 A = C s^{-1}

Gas constants: R = 8.314 (10^7) erg mol^{-1} K^{-1} = 8.314 L kPa mol^{-1} K^{-1}

= 0.08206 L atm mol^{-1} K^{-1} = 8.314 J mol^{-1} K^{-1}

= 1.987 cal mol^{-1} K^{-1} = 8.314 kg m^2 s^{-2} mol^{-1} K^{-1}

Planck's Constant = $6.626218*10^{-34}$ J sec Speed of light = $2.997925*10^8$ m sec^{-1}

Avogadro's Number = $6.022*10^{23}$

Boltzmann constant: k_B = 1.381 (10^{-16}) erg $molecule^{-1}$ K^{-1}

Faraday F = 96,485 coulombs mol^{-1}

MARKS WILL BE DEDUCTED FOR:

- incorrect answers,
- simple math errors,
- synthesis flaws,
- poorly presented solutions,
- hard to follow solutions,
- lack of a clearly stated Basis;
- lack of a clearly outlined flow diagram or sketch of the process;
- incorrect units, or
- improper use of significant figures.

Do all FIVE of the following Questions

NAME:________________________________

Problem 1 (10 Marks)

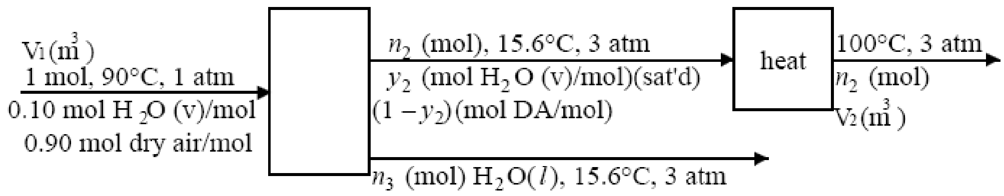
Water flows from an elevated reservoir, through a pipe, to a turbine at a lower level, then out of the turbine through a similar pipe. At a point 100 m above the turbine the pressure is 207 kPa, and at a point 3 m below the turbine the pressure is 124 kPa. Use a mechanical energy balance to determine what the water flow rate must be if the turbine output is 1×10^5 W? Assume no friction losses.

Data: Density of water is 1000 kg/m^3

Problem 2 (10 Marks)

Air at 90°C and 1 atm (absolute) contains 10 mole% water. A continuous stream of this air enters a condenser, in which the temperature is lowered to 15.6°C and the pressure is raised to 3 atm. The air leaving the condenser is then heated at constant pressure to 100°C. Calculate the fraction of water that is condensed from the air and the relative humidity of the air at 100°C.

6.18 Basis: 1 mol feed



Saturation: $y_2 = \dfrac{p^*_{H_2O}(15.6^\circ C)}{P} \xRightarrow{\text{Table B.3}} y_2 = \dfrac{13.29 \text{ mm Hg}}{3 \text{ atm}} \left| \dfrac{\text{atm}}{760 \text{ mm Hg}} \right. = 0.00583$

Dry air balance: $0.90(1) = n_2(1 - 0.00583) \Rightarrow n_2 = 0.9053 \text{ mol}$

H_2O mol balance: $0.10(1) = 0.00583(0.9053) + n_3 \Rightarrow n_3 = 0.0947 \text{ mol}$

Fraction H_2O condensed: $\dfrac{0.0947 \text{ mol condensed}}{0.100 \text{ mol fed}} = 0.947 \text{ mol condense/mol fed}$

$$h_r = \frac{y_2 P \times 100\%}{p^*(100^\circ C)} = \frac{0.00583(3 \text{ atm})}{1 \text{ atm}} \times 100\% = 1.75\%$$

Problem 3 (12 Marks)

8.28

On a warm winter day the temperature is 2°C and the relative humidity is 15%. You inhale air at an average rate of 5500 mL/min and exhale a gas saturated with water at body temperature, 37°C. If the mass flow rates of the inhaled and exhaled air (excluding water) are the same, the heat capacity of dry air is 1.05 J/g °C, and water exists in your body as a liquid at 22°C, at what rate in J/day do you loose energy by breathing? Treat breathing as a continuous process and neglect work done by the lungs.

Heat capacity of liquid water = , Cp Water Vapour = , Heat of vapourization of water(22°C)

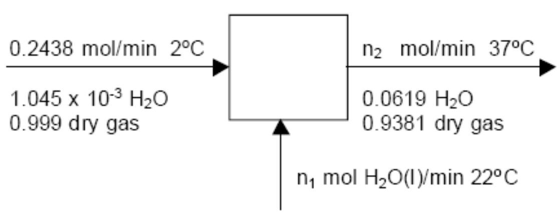
ANTOINE'S CONSTANTS:	A	B	C
Water:	7.96681	1668.21	228

8.28 2°C, 15% rel. humidity $\Rightarrow p_{H_2O} = (0.15)(5.294 \text{ mm Hg}) = 0.7941 \text{ mm Hg}$

$$\left(y_{H_2O}\right)_{\text{inhaled}} (0.7941)/(760) = 1.045 \times 10^{-3} \text{ mol } H_2O/\text{mol inhaled air}$$

$$\dot{n}_{\text{inhaled}} = \frac{5500 \text{ ml}}{\text{min}} \left| \frac{273 \text{ K}}{275 \text{ K}} \right| \frac{1 \text{ liter}}{10^3 \text{ ml}} \left| \frac{1 \text{ mol}}{22.4 \text{ liters(STP)}} \right. = 0.2438 \text{ mol air inhaled/min}$$

Saturation at 37 °C $\Rightarrow y_{H_2O} = \dfrac{p^*(37°\text{C})}{760 \text{ mm Hg}} = \dfrac{47.067}{760} = 0.0619 \text{ mol } H_2O/\text{mol exhaled dry gas}$



Mass of dry gas inhaled (and exhaled) $= \dfrac{(0.2438)(0.999)\text{mol dry gas}}{\text{min}} \left| \dfrac{29.0 \text{ g}}{\text{mol}} \right. = 7.063 \text{ g/min}$

Dry gas balance: $(0.999)(0.2438) = 0.9381\, \dot{n}_2 \Rightarrow \dot{n}_2 = 0.2596 \text{ mols exhaled/min}$

H_2O balance: $(0.2438)(1.045 \times 10^{-3}) + \dot{n}_1 = (0.2596)(0.0619) \Rightarrow \dot{n}_1 = 0.0158 \text{ mol } H_2O/\text{min}$

References for enthalpy calculations: $H_2O(l)$ at triple point, dry gas at 2 °C

substance	$\dot{m}_{in}$	$\hat{H}_{in}$	$\dot{m}_{out}$	$\hat{H}_{out}$
Dry gas	7.063	0	7.063	36.75
$H_2O(v)$	0.00459	2505	0.290	2569
$H_2O(l)$	0.285	92.2	—	—

$\dot{m}$ in g/min $\quad \dot{m}_{H_2O} = 18.02\dot{n}_{H_2O}$

$\hat{H}$ in J/g $\quad \hat{H}_{H_2O}$ from Table 8.4

$\hat{H}_{\text{dry gas}} = 1.05(T-2)$

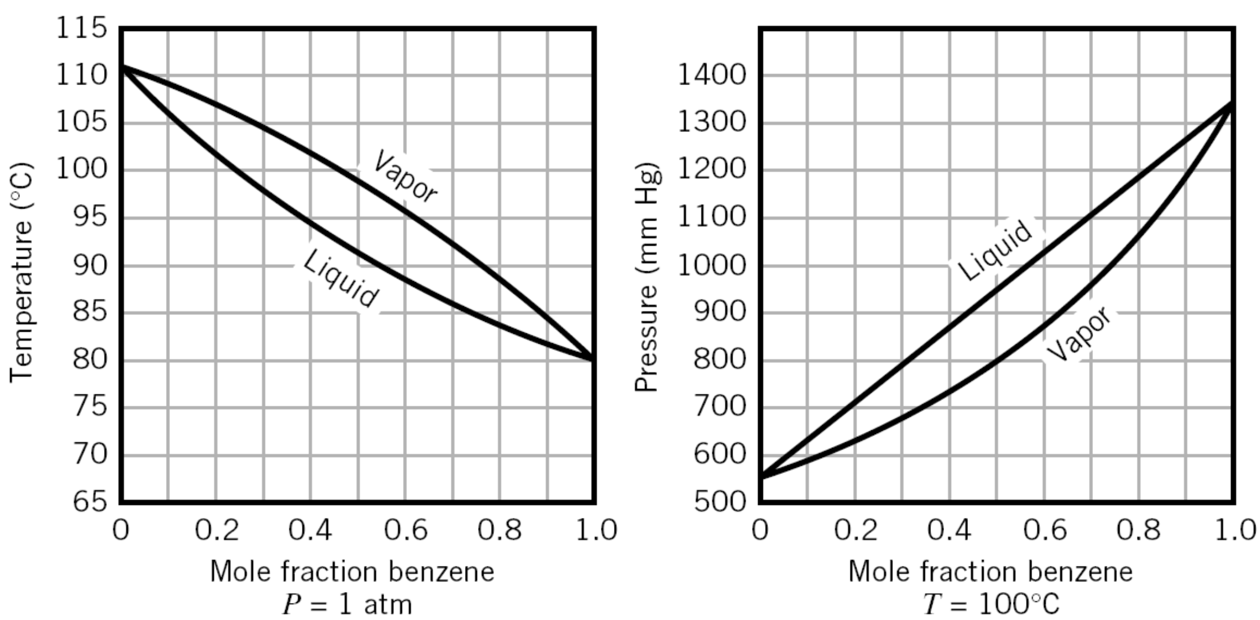
$$Q = \Delta H = \sum_{\text{out}} \dot{m}_i \hat{H}_i - \sum_{\text{in}} \dot{m}_i \hat{H}_i = \frac{966.8 \text{ J}}{\text{min}} \left| \frac{60 \text{ min}}{1 \text{ hr}} \right| \frac{24 \text{ hr}}{1 \text{ day}} = 1.39 \times 10^6 \text{ J/day}$$

Problem 4 (14 Marks)

Eg.

100 mols of an equimolar liquid mixture of benzene and toluene at 10°C and 760 mm Hg is fed continuously to a vessel in which the mixture is heated to 50°C. What is the heating requirement of the heater?

Data: $C_{p\ Benzene,\ l}$ = , $C_{p\ Benzene,\ v}$, $C_{p\ Toluene,\ l}$, $C_{p\ Toluene,\ v}$, $\Delta\hat{H}_{vap,Benzene}(80.1\,^{\circ}C) =$, $\Delta\hat{H}_{vap,Toluene}(110\,^{\circ}C) =$



(a) Txy diagram (b) Pxy diagram

Problem 5 (14 Marks)
9.36

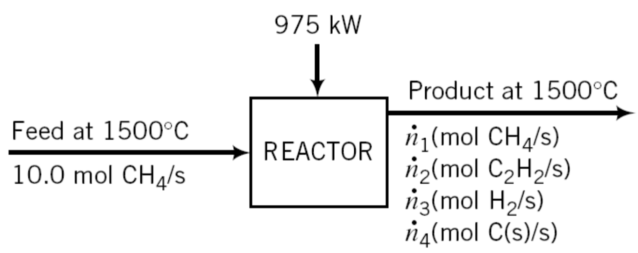
You are checking the performance of a reactor in which acetylene is produced from methane in the reaction

$$2\ CH_4\ (g) \rightarrow C_2H_2\ (g) + 3H_2\ (g)$$

An undesired side reaction is the decomposition of acetylene:

$$C_2H_2 \rightarrow 2C\ (s) + H_2\ (g)$$

Methane is fed to the reactor at 1500 °C at a rate of 10.0 mol CH_4/s. Heat is transferred to the reactor at a rate of 975 kW. The product temperature is 1500 °C and the fractional conversion of methane is 0.600.



Determine the molar flow rates of the product components and the yield of acetylene (mol C_2H_2 produced/mol CH_4 consumed).

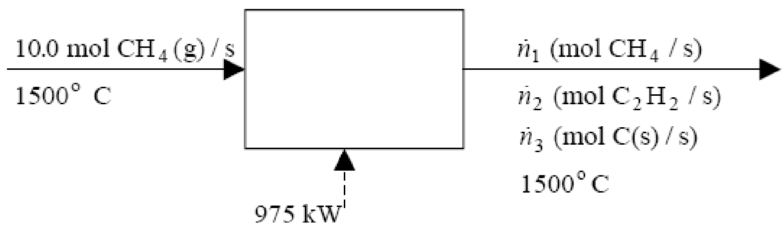
DATA: Cp, heat of formations

9.36

$2CH_4 \rightarrow C_2H_2 + 3H_2$

$C_2H_2 \rightarrow 2C(s) + H_2$

Basis: 10 mol $CH_4(g)$ fed/s



a.

60% conversion $\Rightarrow \dot{n}_1 = 10(1-0.600) = \underline{\underline{4.00 \text{ mol } CH_4/s}}$

C balance: $10(1) = 4(1) + 2\dot{n}_2 + \dot{n}_4 \Rightarrow 2\dot{n}_2 + \dot{n}_4 = 6$ (1)

H balance: $10(4) = 4(4) + 2\dot{n}_2 + 2\dot{n}_3 \Rightarrow 2\dot{n}_2 + 2\dot{n}_3 = 24$ (2)

References for enthalpy calculations : C(s), $H_2(g)$ at 25°C

$H_i = \left(\Delta\hat{H}_f^\circ\right)_i + C_{pi}(1500-25)$, $i = CH_4, C_2H_2, C, H_2$

Substance	$\dot{n}_{in}$ (mol/s)	$\hat{H}_{in}$ (kJ/mol)	$\dot{n}_{out}$ (mol/s)	$\hat{H}_{out}$ (kJ/mol)
$CH_4(g)$	10	41.68	4	41.68
$C_2H_2(g)$	–	–	$\dot{n}_2$	303.45
$H_2(g)$	–	–	$\dot{n}_3$	45.72
C(s)	–	–	$\dot{n}_4$	32.45

Energy Balance: $Q = \Delta H \Rightarrow 975 \text{ kJ/s} = \sum_{out} \dot{n}_i \hat{H}_i - \sum_{in} \dot{n}_i \hat{H}_i$ (3)

Solve (1) - (3) simultaneously $\Rightarrow \begin{cases} \dot{n}_2 = \underline{\underline{2.50 \text{ mol } C_2H_2/s}} \\ \dot{n}_3 = \underline{\underline{9.50 \text{ mol } H_2/s}} \\ \dot{n}_4 = \underline{\underline{1.00 \text{ mol C/s}}} \end{cases}$

Yield of acetylene $= \dfrac{2.50 \text{ mol } C_2H_2/s}{6.00 \text{ mol } CH_4 \text{ consumed}/s} = \underline{\underline{0.417 \text{ mol } C_2H_2/\text{mol } CH_4 \text{ consumed}}}$