Seat No.

King Mongkut's University of Technology Thonburi
Final Examination—1/2557
CHE 104 Fundamentals Material and Energy Balances
The 2nd year stduents: Department of Chemistry

Date: 3 DEC 2014, 13:00-16:00 pm.

Notes:

1. This exam paper includes 5 problems (100 points) in a total of 11 pages, do in the examination sheet.
2. It is a closed-book/notes examination.
3. A calculator is allowed.
4. Students are not allowed to take any exam materials/papers out of the exam room.
5. The gas constant, Factors for unit conversions, Atomic weights and some useful equations are provided on pages 9-11.
6. Appendix B is providcd in separated sheets.

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Written by
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This exam paper has been evaluated and approved by the Department of Chemical Engineering's Committee.

(Assoc. Prof. Dr. Piyabutr Wanichpongpan)
Departmental Chair

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1. (30 points)

1.1 To recover heat, a cooler is used to cool a flue gas from 200 °C to 50 °C in which some of water vapor is condensed. The flue gas composes of 2,090 kmol/h N_2, 300 kmol/h CO_2 and 400 kmol/h H_2O (v) in which 1,100 kg/h of water vapor is condensed at the cooler. Calculate the heat that can be recovered from the flue gas.

1.2 If 313,438.9 kg/h of n-hexane at 30 °C and 1 atm is used to cool the flue gas in the question 1.1), calculate the outlet temperature of hexane.

Answer
1.1 ....kW
1.2 ....°C

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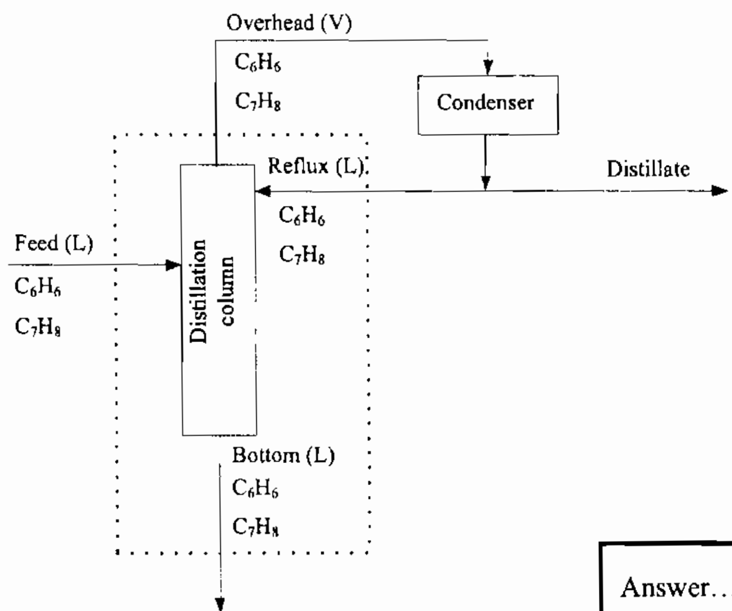
2. (20 points) The benzene/toluene mixture is separated in a distillation column as shown in the figure below. The composition and temperature of each stream are shown in the table below. Calculate the heat required for the distillation column.

	Feed kmol/s	Overhead kmol/s	Reflux kmol/s	Bottom kmol/s	Distillate kmol/s
Benzene	6	17.85	11.9	0.05	5.95
Toluene	4	0.3	0.2	3.9	0.1
Temp (°C)	25	82	70	90	



Answer..............................kW

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3. (14 points) Determine the following properties of steam or water relative to water (l) at triple point.

   3.1 Enthalpy of water (l) at 38 ^{o}C and 1 atm (abs).

   3.2 Latent heat of vaporization of water at 182.0 ^{o}C.

   3.3 Enthalpy of steam at 5 bar (abs) and 190 ^{o}C

   3.4 Heat release for the process of converting 4 ton/h of saturated steam at 10 bar (abs) to a condensate at 80 ^{o}C and 1 atm.

Answer

3.1............................kJ/kg

3.2............................kJ/kg

3.3............................kJ/kg

3.4............................kW

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4. (6 points) Determine the standard heat of reaction (at 25 °C) of the following reactions. Fill your answer in the right boxes.

Answer
4.1............................kJ/mol
4.2............................kJ/mol

$$\Delta H_r^o = \sum_{\text{products}} \nu_i \Delta H_{fi}^o - \sum_{\text{reactants}} \nu_i \Delta H_{fi}^o$$

$$\Delta H_r^o = \sum_{\text{reactants}} \nu_i \Delta H_{ci}^o - \sum_{\text{products}} \nu_i \Delta H_{ci}^o$$

4.1 $CH_4(g) + O_2(g) \rightarrow HCHO\ (g) + H_2O\ (g)$

4.2 $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O\ (g)$

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5. (30 points) Formaldehyde (HCHO) is prepared by oxidation of methane. The side reaction is the combustion of the methane to be CO_2 and H_2O as follows.

$$CH_4(g) + O_2(g) \rightarrow HCHO\ (g) + H_2O\ (g) \qquad 1)$$
$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O\ (g) \qquad 2)$$

CH_4 100 mol/s at 25 °C and air 500 mol/s at 35 °C are fed to a reactor. The gas mixture leaving the reactor at 500 °C composes of N_2 395 mol/s, HCHO 95 mol/s, H_2O 105 mol/s and CO_2 5 mol/s. Determine the heat that must be transferred to or from the reactor?

Answer............................kW

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THE GAS CONSTANT

8.314 $m^3 \cdot Pa/(mol \cdot K)$
0.08314 $L \cdot bar/(mol \cdot K)$
0.08206 $L \cdot atm/(mol \cdot K)$
62.36 $L \cdot mm\ Hg/(mol \cdot K)$
0.7302 $ft^3 \cdot atm/(lb\text{-}mole \cdot °R)$
10.73 $ft^3 \cdot psia/(lb\text{-}mole \cdot °R)$
8.314 $J/(mol \cdot K)$
1.987 $cal/(mol \cdot K)$
1.987 $Btu/(lb\text{-}mole \cdot °R)$

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 $kg \cdot m/s^2$ = 10^5 dynes = 10^5 $g \cdot cm/s^2$ = 0.22481 lb_f 1 lb_f = 32.174 $lb_m \cdot ft/s^2$ = 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 $N \cdot m$ = 10^7 ergs = 10^7 $dyne \cdot cm$ = 2.778×10^{-7} $kW \cdot h$ = 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 $ft \cdot lb_f/s$ = 9.486×10^{-4} Btu/s = 1.341×10^{-3} hp

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

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ATOMIC WEIGHTS AND NUMBERS

Atomic weights apply to naturally occurring isotopic compositions and are based on an atomic mass of $^{12}C = 12$

Element	Symbol	Atomic Number	Atomic Weight	Element	Symbol	Atomic Number	Atomic Weight
Actinium	Ac	89	—	Iridium	Ir	77	192.2
Aluminum	Al	13	26.9815	Iron	Fe	26	55.847
Americium	Am	95	—	Krypton	Kr	36	83.80
Antimony	Sb	51	121.75	Lanthanum	La	57	138.91
Argon	Ar	18	39.948	Lawrencium	Lr	103	—
Arsenic	As	33	74.9216	Lead	Pb	82	207.19
Astatine	At	85	—	Lithium	Li	3	6.939
Barium	Ba	56	137.34	Lutetium	Lu	71	174.97
Berkelium	Bk	97	—	Magnesium	Mg	12	24.312
Beryllium	Be	4	9.0122	Manganese	Mn	25	54.9380
Bismuth	Bi	83	208.980	Mendelevium	Md	101	—
Boron	B	5	10.811	Mercury	Hg	80	200.59
Bromine	Br	35	79.904	Molybdenum	Mo	42	95.94
Cadmium	Cd	48	112.40	Neodymium	Nd	60	144.24
Calcium	Ca	20	40.08	Neon	Ne	10	20.183
Californium	Cf	98	—	Neptunium	Np	93	—
Carbon	C	6	12.01115	Nickel	Ni	28	58.71
Cerium	Ce	58	140.12	Niobium	Nb	41	92.906
Cesium	Cs	55	132.905	Nitrogen	N	7	14.0067
Chlorine	Cl	17	35.453	Nobelium	No	102	—
Chromium	Cr	24	51.996	Osmium	Os	75	190.2
Cobalt	Co	27	58.9332	Oxygen	O	8	15.9994
Copper	Cu	29	63.546	Palladium	Pd	46	106.4
Curium	Cm	96	—	Phosphorus	P	15	30.9738
Dysprosium	Dy	66	162.50	Platinum	Pt	78	195.09
Einsteinium	Es	99	—	Plutonium	Pu	94	—
Erbium	Er	68	167.26	Polonium	Po	84	—
Europium	Eu	63	151.96	Potassium	K	19	39.102
Fermium	Fm	100	—	Praseodymium	Pr	59	140.907
Fluorine	F	9	18.9984	Promethium	Pm	61	—
Francium	Fr	87	—	Protactinium	Pa	91	—
Gadolinium	Gd	64	157.25	Radium	Ra	88	—
Gallium	Ga	31	69.72	Radon	Rn	86	—
Germanium	Ge	32	72.59	Rhenium	Re	75	186.2
Gold	Au	79	196.967	Rhodium	Rh	45	102.905
Hafnium	Hf	72	178.49	Rubidium	Rb	37	84.57
Helium	He	2	4.0026	Ruthenium	Ru	44	101.07
Holmium	Ho	67	164.930	Samarium	Sm	62	150.35
Hydrogen	H	1	1.00797	Scandium	Sc	21	44.956
Indium	In	49	114.82	Selenium	Se	34	78.96
Iodine	I	53	126.9044	Silicon	Si	14	28.086

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Element	Symbol	Atomic Number	Atomic Weight	Element	Symbol	Atomic Number	Atomic Weight
Silver	Ag	47	107.868	Tin	Sn	50	118.69
Sodium	Na	11	22.9898	Titanium	Ti	22	47.90
Strontium	Sr	38	87.62	Tungsten	W	74	183.85
Sulfur	S	16	32.064	Uranium	U	92	238.03
Tantalum	Ta	73	180.948	Vanadium	V	23	50.942
Technetium	Tc	43	—	Xenon	Xe	54	131.30
Tellurium	Te	52	127.60	Ytterbium	Yb	70	173.04
Terbium	Tb	65	158.924	Yttrium	Y	39	88.905
Thallium	Tl	81	204.37	Zinc	Zn	30	65.37
Thorium	Th	90	232.038	Zirconium	Zr	40	91.22
Thulium	Tm	69	168.934				

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Determine of heat reaction

$$\Delta H_r^o = \sum_{\text{products}} \nu_i \Delta H_{fi}^o - \sum_{\text{reactants}} \nu_i \Delta H_{fi}^o$$

$$\Delta H_r^o = \sum_{\text{reactants}} \nu_i \Delta H_{ci}^o - \sum_{\text{products}} \nu_i \Delta H_{ci}^o$$

Heat of reaction method,

$$Q = \Delta H = \sum_{\text{out}} n_i H_i + \sum_{\text{reaetion}} \xi_j \Delta H_{r\,j}^o - \sum_{\text{in}} n_i H_i$$

$$H_i = \int_{25}^{T} (c_p)_i \, dT$$

$$\xi = \frac{n_{i,r}}{\nu_i}$$

Heat of formation method,

$$Q = \Delta H = \sum_{out} n_i H_i - \sum_{in} n_i H_i$$

$$H_{i,in,out} = (\Delta H_f^o)_i + \int_{25\,^\circ C}^{T} Cp_i \, dT$$