Seat No.

King Mongkut's University of Technology Thonburi
Midterm Examination—2/2558
ChE 103 Material and Energy Balances
1st year student, Department of Chemical Engineering

Date: 29 FEB 2016, 13.00-16.00 pm

Notes:

1. This exam paper includes 6 problems (100 points) in a total of 12 pages.
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. Write your answers on the examination sheets.
6. Some useful data are given on pages 9-12 and Appendix B.

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Written by
Asst. Prof. Dr. Ampai Chanachai

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

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(Assoc. Prof. Dr. Piyabutr Wanichpongpan)
Head of Department

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1. (10 points) Ammonia is oxidized in a continuous reactor:

$$4NH_3\ (g) + 5O_2\ (g) \rightarrow 4NO\ (g) + 6H_2O\ (g)$$

100 kg/h of NH_3 gas and oxygen with 10 % excess are fed to the reactor. The percentage conversion of NH_3 is 96 %. Determine the composition and molar flow rate of the exit gas.

2. (20 points) Ammonia is oxidized in a continuous reactor:

$$4NH_3\ (g) + 5O_2\ (g) \rightarrow 4NO\ (g) + 6H_2O\ (g)$$

Air and 1,700 kg/h of NH_3 gas are fed to the reactor. The percentage conversion of NH_3 is 92 %. The composition of O_2 in the exit gas is 3 % mol (dry basis). Determine the molar flow rate of the air fed to the reactor.

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3. (25 points) Acetylene is produced from methane in the reaction:

$$2CH_4\ (g) \rightarrow C_2H_2\ (g) + 3H_2\ (g) \qquad (3.1)$$

An undesired reaction is the decomposition of acetylene:

$$C_2H_2\ (g) \rightarrow 2C\ (s) + H_2\ (g) \qquad (3.2)$$

100 mol/s of methane is fed to a reactor. The %yield of acetylene is 80%. The mole fraction of C_2H_2 in the exiting gas is 0.208.

3.1 Draw a simplified flow chart. Label all unknowns.
3.2 Perform the degree of freedom analysis.
3.3 Determine the percentage conversion of methane.
3.4 Determine the mass of C (s) occurs.
3.5 Determine the extent of reaction (3.1) and (3.2).

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4. (10 points) The product gas of hexane combustion composes of 75.4% N_2, 13.67 %CO_2, 1.87 % O_2 and the balance H_2O. The stack gas emerges at 760 mm Hg. Determine the dew point of the stack gas, taking the water to be the only condensable component.

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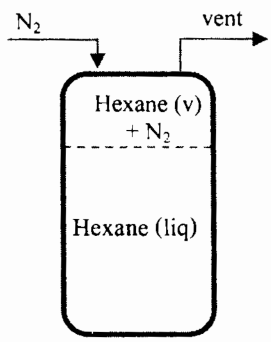
5. (15 points) Liquid n-Hexane is stored in a cylindrical tank with 5 m in diameter and 10 m high. The pressure in the tank is controlled at 0.2 bar gauge. If the pressure is lower than 0.2 bar gauge, the N_2 gas is filled into the gas mixture over liquid but if it is higher than 0.2 bar gauge, the gas mixture over liquid will release through the vent line.

   In one night, the temperature in the tank is at 25 °C and the liquid hexane volume is 80% of the tank volume. However, on the day time, the temperature in the tank increases to 35 °C leading to some gas venting through the vent line. Determine the hexane vapor loss due to an increasing of temperature from 25 °C to 35 °C. Assumed that the gas mixture over liquid is saturated with hexane vapor at that temperature.



6. (20 points) Humid air with 90% relative humidity (%RH) at 100 °C and 2 atm is humidified by cooling and compressing air to 50 °C and 3 atm. Then, it is reheated and decompressed to the former condition (100 °C and 2 atm). For 1 kg of dry air (DA),

   6.1 Determine % condensation of water

   6.2 Determine %RH of the exit air at 100 °C and 2 atm.

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Useful information:

$$\% \text{ excess } = \frac{(n_i)_{\text{fed}} - (n_i)_{\text{theoretical}}}{(n_i)_{\text{theoretical}}} \times 100\%$$

$$\xi = \frac{|n_{i,\text{out}} - n_{i,\text{in}}|}{\nu_i} \qquad \xi = \text{extent of reaction}$$

$$\textbf{Yield} = \frac{\text{moles of desired product formed}}{\text{moles desired product formed if there were no side reactions and the limiting reactant had reacted completely}}$$

$$\text{overall conversion} = \frac{\text{mole reactant input to process - mole reactant output from process}}{\text{mole reactant input to process}}$$

$$\text{Single pass conversion} = \frac{\text{mole reactant input to reactor - mole reactant output from reactor}}{\text{mole reactant input to reactor}}$$

$$p_i (= y_i P) = x_i p_i^*$$

$$s_r(h_r) = \frac{y_i}{y_i^*} = \frac{p_i}{p_i^*} = \frac{\rho_i}{\rho_i^*} = \frac{V_i^*}{V_i}$$

$$s_a(h_a) = \frac{\text{mass of vapor}}{\text{mass of dry gas}} = \frac{m_i}{m_{\text{dry gas}}} = \frac{p_i (MW)_i}{p_{\text{dry}} (MW)_{\text{dry}}} = \frac{p_i (MW)_i}{(P - p_i)(MW)_{\text{dry}}}$$

$$s_p(h_p) = \frac{s_m}{s_m^*} \times 100\% = \frac{p_i / (P - p_i)}{p_i^* / (P - p_i^*)} = \left(\frac{p_i}{p_i^*}\right)\left(\frac{P - p_i^*}{P - p_i}\right)$$

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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				

THE GAS CONSTANT

$8.314\ m^3 \cdot Pa/(mol \cdot K)$

$0.08314\ L \cdot bar/(mol \cdot K)$

$0.08206\ L \cdot atm/(mol \cdot K)$

$62.36\ L \cdot mm\ Hg/(mol \cdot K)$

$0.7302\ ft^3 \cdot atm/(lb\text{-}mole \cdot {}^\circ R)$

$10.73\ ft^3 \cdot psia/(lb\text{-}mole \cdot {}^\circ R)$

$8.314\ J/(mol \cdot K)$

$1.987\ cal/(mol \cdot K)$

$1.987\ Btu/(lb\text{-}mole \cdot {}^\circ R)$

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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 $\left(\frac{2.20462\ lb_m}{1000\ g}\right)$.