

## 16-CHEM-A1, PROCESS BALANCES and CHEMICAL THERMODYNAMICS

MAY 2019

Three Hours Duration

### NOTES:

- 1) If doubt exists as to the interpretation of any question, you are urged to submit a clear statement of any assumptions made along with the answer paper.
- 2) Property data required to solve a given problem are provided in the problem statement or are available in the recommended texts. If you are unable to locate the required data, do not let this prevent you from solving the rest of the problem. Even in the absence of property data, you still have the opportunity to provide a solution methodology.
- 3) This is an open-book exam. Any non-communicating calculator is permitted.
- 4) The examination is in two parts – Part A (Questions 1 to 3): Process Balances  
Part B (Questions 4 and 6): Chemical Thermodynamics
- 5) Answer **TWO** questions from Part A and **TWO** questions from Part B.
- 6) **FOUR** questions constitute a complete paper.
- 7) Each question is of equal value.

**PART A: PROCESS MASS and ENERGY BALANCES**

1) An air-conditioning plant is used to maintain a dry-bulb temperature of 27 °C and relative humidity of 50% in an auditorium. The air flow rate to the auditorium is 20,900 m<sup>3</sup>/hr at a dry-bulb temperature of 17 °C and relative humidity of 83.5%. The effluent air from the auditorium is partially recycled and mixed with the incoming fresh air, which is fed at a rate of 4,500 m<sup>3</sup>/hr at a dry-bulb temperature of 35 °C and relative humidity of 70%. The mixed air, which has a dry-bulb temperature of 29.5 °C and relative humidity of 54%, is passed through the air-conditioning plant to make it suitable for feeding to the auditorium. The total pressure can be assumed to be constant at 1 atm (101.325 kPa).

(a) [11 points] Calculate the moisture removed in the air-conditioning plant.

(b) [3 points] Calculate the moisture added in the auditorium.

(c) [11 points] Calculate the recycle ratio (moles of air recycled per mole of input fresh air)

DATA:

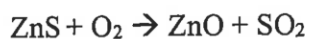
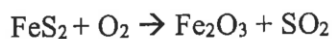
Absolute molar humidity of fresh air at 35 °C =  $4.05 \times 10^{-2}$  moles per mole of dry air

Absolute molar humidity of mixed air at 29.5 °C =  $2.25 \times 10^{-2}$  moles per mole of dry air

Absolute molar humidity of air entering the auditorium at 17 °C =  $1.63 \times 10^{-2}$  moles per mole of dry air

Absolute molar humidity of air leaving the auditorium at 27 °C =  $1.81 \times 10^{-2}$  moles per mole of dry air

- 2) A mixture containing 75% iron pyrite ( $\text{FeS}_2$ ) ore and 25% zinc sulfide ( $\text{ZnS}$ ) ore by weight are burnt in burner. The pyrites yield 92%  $\text{FeS}_2$  and the rest is gangue. The zinc sulfide ore contains 68%  $\text{ZnS}$  and the rest are inerts. A sample of the cinder product yields 3.5% sulfur with 70% of the sulfur in the cinder in the form of  $\text{SO}_3$  absorbed in it and the rest is unoxidized  $\text{FeS}_2$ . The stoichiometrically unbalanced reactions in the burner are as follows:



- (a) [20 points] Calculate the amount of cinder product formed and its composition based on 100 kg of mixed charge to the burner.
- (b) [5 points] Calculate the percentage of sulfur left in the cinder product based on the total sulfur charged.

- 3) A sulfur burner in a sulfite pump mill burns 200 kg of pure sulfur per hour. The gas leaves the burner at 871 °C and they are cooled before being sent to an absorption tower. As a primary cooler, a waste heat boiler is employed for producing saturated steam at a pressure of 15 bars (absolute). The feed water to the boiler is available at 183 °C and the temperature of the gas mixture leave the boiler is 190 °C. Calculate the amount of steam produced in kg per hour assuming 10% excess air, 90% efficiency, complete combustion, no heat loss to the surroundings and no SO<sub>3</sub> formation.

DATA:

Standard molar specific heat capacity of SO<sub>2</sub> in kJ/kmol.K =  $24.7706 + 62.9841 \times 10^{-3} T - 4.42582 \times 10^{-5} T^2 + 11.122 \times 10^{-9} T^3$

Standard molar specific heat capacity of O<sub>2</sub> in kJ/kmol.K =  $26.0257 + 11.7551 \times 10^{-3} T - 2.3426 \times 10^{-6} T^2 - 56.23 \times 10^{-11} T^3$

Standard molar specific heat capacity of N<sub>2</sub> in kJ/kmol.K =  $29.5909 + 51.141 \times 10^{-4} T - 1.31829 \times 10^{-5} T^2 - 49.68 \times 10^{-10} T^3$

Saturation temperature of steam at 15 bars pressure = 198 °C

Latent heat of vaporization of water at 15 bars pressure = 1945 kJ/kg

Specific heat capacity of water = 4.1868 kJ/kg.K

**PART B: CHEMICAL THERMODYNAMICS**

- 1) Water gas, available at a temperature of 500 °C and a pressure 4 bar, has the following composition: 70.4 grams of hydrogen, 23.68 grams of methane, 35.84 grams of ethylene, 66 grams of carbon dioxide, 94.92 grams of carbon monoxide and 50.4 grams of nitrogen.

(a) [5 points] Calculate the volume of water gas if it behaves as an ideal gas.

(b) [20 points] Calculate the volume of water gas if it follows van der Waals equation of state.

DATA:

Component	Formula	Critical Temperature (K)	Critical Pressure (bar)
Hydrogen	H <sub>2</sub>	32.2	12.97
Methane	CH <sub>4</sub>	190.56	45.99
Ethylene	C <sub>2</sub> H <sub>4</sub>	282.34	50.41
Carbon Monoxide	CO	132.91	34.99
Carbon Dioxide	CO <sub>2</sub>	304.1	73.75
Nitrogen	N <sub>2</sub>	126.9	33.94

- 2) Pyrites are roasted in a roaster plant for making sulfuric acid. The gases leave the roaster at 502 °C with the mass composition: 3.57% SO<sub>2</sub>, 1.08% O<sub>2</sub>, 0.18% SO<sub>3</sub> and the rest N<sub>2</sub>. Calculate the heat content of 1 kmol of gas mixture over 25 °C.

DATA:

Standard molar specific heat capacity of SO<sub>2</sub> in kJ/kmol.K =  $24.7706 + 62.9841 \times 10^{-3} T - 4.42582 \times 10^{-5} T^2 + 11.122 \times 10^{-9} T^3$

Standard molar specific heat capacity of O<sub>2</sub> in kJ/kmol.K =  $26.0257 + 11.7551 \times 10^{-3} T - 2.3426 \times 10^{-6} T^2 - 56.23 \times 10^{-11} T^3$

Standard molar specific heat capacity of SO<sub>3</sub> in kJ/kmol.K =  $22.0376 + 12.1624 \times 10^{-2} T - 9.18673 \times 10^{-5} T^2 - 24.3691 \times 10^{-9} T^3$

Standard molar specific heat capacity of N<sub>2</sub> in kJ/kmol.K =  $29.5909 + 51.141 \times 10^{-4} T - 1.31829 \times 10^{-5} T^2 - 49.68 \times 10^{-10} T^3$

- 3) 2 moles of methane ( $\text{CH}_4$ ) and 3 moles of water react and gaseous mixture containing  $\text{CH}_4$ ,  $\text{H}_2\text{O}$ ,  $\text{CO}$ ,  $\text{CO}_2$  and  $\text{H}_2$  is obtained. Calculate the equilibrium composition of the mixture at 1000 K and 1 atmosphere.

DATA:

Standard Gibbs free energy of formation of  $\text{CH}_4$  at 1000 K = 19.3 kJ/mole

Standard Gibbs free energy of formation of  $\text{H}_2\text{O}$  at 1000 K = - 192.72 kJ/mole

Standard Gibbs free energy of formation of  $\text{CO}$  at 1000 K = - 200.715 kJ/mole

Standard Gibbs free energy of formation of  $\text{CO}_2$  at 1000 K = - 396.11 kJ/mole

Standard Gibbs free energy of formation of  $\text{H}_2$  at 1000 K = 0 kJ/mole

# The Periodic Table of the Elements

Hydrogen 1 H 1.01	Element name → Mercury <b>80</b> ← Atomic #																Helium 2 He 4.00
Lithium 3 Li 6.94	Symbol → <b>Hg</b> ← Avg. Mass <b>200.59</b>																Neon 10 Ne 20.18
Sodium 11 Na 22.99																	Argon 18 Ar 39.95
Potassium 19 K 39.10																	Krypton 36 Kr 83.80
Rubidium 37 Rb 85.47																	Xenon 54 Xe 131.29
Cesium 55 Cs 132.91																	Raon 86 Rn (222)
Francium 87 Fr (223)																	Ununseptium 117 Uus (294?)
																	Ununhexium 116 Uuh (293)
																	Ununpentium 115 Uup (288)
																	Ununquadium 114 Uuq (289)
																	Ununtrium 113 Uut (284)
																	Copernicium 112 Cn (285)
																	Roentgenium 111 Rg (280)
																	Darmstadtium 110 Ds (281)
																	Mendelevium 109 Md (276)
																	Hassium 108 Hs (270)
																	Oganesson 118 Og (289)
																	Meitnerium 109 Mt (276)
																	Hassium 108 Hs (270)
																	Darmstadtium 110 Ds (281)
																	Roentgenium 111 Rg (280)
																	Copernicium 112 Cn (285)
																	Ununquadium 114 Uuq (289)
																	Ununpentium 115 Uup (288)
																	Ununhexium 116 Uuh (293)
																	Ununseptium 117 Uus (294?)

- Alkali metals
- Alkaline earth metals
- Transition metals
- Other metals
- Metalloids (semi-metal)
- Nonmetals
- Halogens
- Noble gases

Lanthanum 57 La 138.91	Cerium 58 Ce 140.12	Praseodymium 59 Pr 140.91	Neodymium 60 Nd 144.24	Promethium 61 Pm (145)	Samarium 62 Sm 150.36	Europium 63 Eu 151.97	Gadolinium 64 Gd 157.25	Terbium 65 Tb 158.93	Dysprosium 66 Dy 162.50	Erbium 68 Er 167.26	Thulium 69 Tm 168.93	Ytterbium 70 Yb 173.04
Actinium 89 Ac (227)	Thorium 90 Th 232.04	Protactinium 91 Pa 231.04	Uranium 92 U 238.03	Neptunium 93 Np (237)	Plutonium 94 Pu (244)	Americium 95 Am (243)	Curium 96 Cm (247)	Berkelium 97 Bk (247)	Californium 98 Cf (251)	Fermium 100 Fm (257)	Mendelevium 101 Md (258)	Nobelium 102 No (259)

\*lanthanides

\*\*actinides