CHE 31. Introduction to Chemical Engineering

Problem Set 2. Gasses and Phase Equilibrium

(Problems adopted from Elementary Principles of Chemical Process by Felder & Rousseau and Basic Principles and Calculations in Chemical Engineering by Himmelblau and Briggs)

Noted: Unless otherwise stated, the given pressure is absolute.

1. Use the ideal gas equation of state to estimate the molar volume in m^3/mol and the density of air in kg/m^3 at 40^0C and a gauge pressure of 3.0 atm.

   Ans. V = 0.0064 m^3/mol ; ρ = 4.5 kg/m^3

2. One gram-mole of methyl chloride vapor is contained in a vessel at 100^0C and 10 atm. Suppose the actual volume of the vessel is 2.8 liters, what percent error results from assuming ideal gas behavior?

   Ans. 9.3 %

3. The pressure gauge on a 20.0 m^3 tank of nitrogen at 25^0C reads 10 bar. Estimate the mass of nitrogen.

   Ans. 249 kg N_2

4. The volume of a dry box (a closed chamber with dry nitrogen flowing through it) is 2.0 m^3. The dry box is maintained at a slight positive gauge pressure of 10 cm H_2O and room temperature (25^0C). If the contents of the box are to be replaced every five minutes, calculate the mass flow rate of nitrogen in g/min using the ideal gas equation of state.

   Ans. 458 g/min

5. A stream of air enters a 7.50-cm ID pipe at a velocity of 60.0 m/s at 27^0C and 1.80 bar (gauge). At a point downstream, the air flows through a 5.00 cm ID pipe at 60^0C and 1.53 bar (gauge). What is the velocity of the air at this point? Assume ideal gas behavior.

   Ans. 165 m/s

6. Calculate the specific molar volume (in L/gmol) of air at 223 K and 50.0 atm using the Van der Waals equation of state.

   Ans. 0.33114 L/gmol

7. Seven pounds of N_2 at 120^0F are stored in a cylinder having a volume of 0.75 ft^3. Calculate the pressure in atmospheres in the cylinder

a. assuming N2 to be an ideal gas.

Ans. P = 141 atm

b. assuming the pressure can be predicted by van der Waals equation

Ans. P = 139 atm

c. using the compressibilty factor method

Ans. P = 151 atm

d. using the Redlich-Kwong equation of state

Ans. P = 144 atm

8. A gas analyzes 60% methane and 40% ethylene by volume. It is desired to store 12.3 kg of this gas mixture in a cylinder having a capacity of 5.14×10^{-2} m^3 at a maximum temperature of 45^0C. Calculate the pressure inside the cylinder by

a. assuming that the mixture obeys the ideal gas law

Ans. P = 30,400 kPa

b. using the compressibility factor determined by the pseudo critical point method in which $(P_C)_{mixture} = \Sigma P_{Ci} y_i$ and $(T_C)_{mixture} = \Sigma T_{Ci} y_i$

Ans. P = 26,000 kPa

9. One hundred pounds of CO_2 is contained in a 10.0-ft^3 tank. The safety limit of the tank is 1600 psig. Use the generalized equation of state to estimate the maximum permissible gas temperature.

Ans. T = 320^0F

10. A stream of oxygen enters a compressor at 298 K and 1.00 atm at a rate of 127 m^3/h and is compressed to 358 K and 1000 atm. Estimate the volumetric flow rate of compressed O_2, using the compressibility-factor equation of state.

Ans. 0.246 m^3/h

11. A 10-liter cylinder containing oxygen at 175 atm absolute is used to supply O_2 to an oxygen tent. The cylinder can be used until its absolute pressure drops to 1.1 atm. Assuming a constant temperature of 270C, calculate the gram-moles of O2 that can be obtained from the cylinder using the compressibility-factor equation of state. **Ans. 74.3 gmol O_2**

12. The vapor pressure of ethylene glycol at several temperatures is given below:

$T(^0C)$	79.7	105.8	120.0	141.8	178.5	197.3
p* (mm Hg)	5.0	20.0	40.0	100.0	400.0	700.0

Estimate the heat of vaporization of ethylene glycol in kJ/mol. Derive an equation for p* (mm Hg) as a function of T (0C) based on the Clausius-Clapeyron equation.

Ans. $\mathbf{\Delta H_V = 58.8\ kJ/mol\ ;\ p^* = exp\left[\frac{-7076}{T+273.2}+21.67\right]}$

13. Estimate the vapor pressure of acetone (mm Hg) at 50^0C using the Antoine equation.

Ans. p* = 613 mm Hg

14. A gas mixture contains 10.0 mole% water vapor and 90.0 mole% N_2. The initial gas temperature and absolute pressure are 50^0C and 500 mm Hg. Ideal gas behaviour may be assumed.

a. If the gas mixture is put in a cylinder and slowly cooled at constant pressure, at what temperature would the first drop of liquid form?

Ans. T = 38.1 ^{0}C

b. If a 30.0-liter flask is filled with the gas mixture and sealed and the water vapor in the flask is completely condensed, what volume (cm^3) would be occupied by the water.

Ans. V = 1.34 cm^3

15. Pure chlorobenzene is contained in a flask attached to an open –end mercury manometer. When the flask contents are at 58.3^0C, the height of the mercury in the arm of the manometer connected to the flask is 747 mm and that in the arm open to the atmosphere is 52 mm. At 110^0C, the mercury level is 577 mm in the arm connected to the flask and 222 mm in the other arm.

a. Estimate the vapor pressure of chlorobenzene at 130^0C using the Clausius-Clapeyron equation. **Ans. p* = 731 mm Hg**

b. Air saturated with chlorobenzene at 130^0C and 101.3 kPa is cooled to 58.30C at constant pressure. Estimate the percentage of the chlorobenzene that condenses.

Ans. 99.7% of chlorobenze will condense

16. The latest weather report includes the following statement: "The temperature is 780F, barometric pressure is 29.9 inches, and the relative humidity is 87%." From this information, estimate the mole fraction of water in the air and the dew point (0F), molal humidity, and absolute humidity.

    Ans. y_{H2O} = 0.0281 ; dew point = 23.2 0C ; h_m = 0.0289 ; h_a = 0.0180

17. Air at 50% relative humidity is cooled isobarically at 1 atm absolute from 90^0C to 25^0C.

    a. Estimate the dew point and the amount of water condensing (in mol) per cubic meter of air.

       Ans. dew point = 72.7^0C ; 10.9 mol H_2O condense/m^3

    b. Suppose the air is put in a closed variable-volume chamber containing a mirror and the pressure is raised at constant temperature until a mist foms on the mirror. At what pressure (atm) would the mist form? (Assume ideal gas behaviour)

       Ans. P = 2.00 atm

18. Air containing 20.0 mole% water vapor at an initial pressure of 1 atm absolute is cooled in a 1-liter sealed vessel from 200^0C to 15^0C.

    a. What is the pressure in the vessel at the end of the process? (You may neglect the volume of the liquid water condensed, but you must show that condensation ocurs)

       Ans. P = 383 mm Hg

    b. What is the mole fraction of water in the gas phase at the end of the process?

       Ans. y_{H2O} = 0.03339

    c. How much water (in grams) condenses?

       Ans. 0.0802 g