Chemical Engineering 140 **December 14, 2009**

Final Examination

(135) 1. Liquid hydrazine (N_2H_4) is injected into a jet combustion chamber at 400 K and burned with 100 % excess air that enters at 700 K. The combustion chamber is jacketed with water. The combustion products leave the jet exhaust at 900 K. In the test, 50 kmol of hydrazine are burned per hour. Water at 25 °C enters the water jacket for cooling at a mass flow rate of 40 kg/min. The reaction is

$$N_2H_4(l) + O_2(g) \longrightarrow N_2(g) + H_2O(g)$$

Data: $\Delta\tilde{H}_f^o$ of $N_2H_4(l)$ = 44.77 kJ/gmol; $\tilde{C}_p$ of $N_2H_4(l)$ = 139 J/gmol°C

(95) a. What is the volumetric flow rate of water out of the cooling jacket (at 1 atm)?

(20) b. The diameter for the water jacket inlet is 0.1 m, and the diameter for the jacket outlet is 0.03 m. The water jacket outlet is 2 m below the jacket inlet. Are the kinetic and potential energy changes for the water significant?

(20) c. If the water flow were halted, what would be the temperature of the outlet gas from the reactor? The reactor is made of nickel, which melts at 1453 °C. Is this a problem? What design features should the reactor have to mitigate the effects of this possible accident?

(165) 2. An ideal gas resides in a piston-cylinder initially at temperature T_o, pressure P_o, and volume, V_o, as illustrated in Figure 2 below. At zero time, heat is supplied according to Newton's law, $\underline{\dot{Q}} = \underline{U}A(T_a - T)$, where $\underline{U}$ is the overall heat transfer coefficient, A is the heat-transfer area of the cylinder, T_a is the constant temperature of the environment, and T is the well-mixed temperature of the gas. T_a is larger than T_o. During heating, the pressure on the piston remains constant at P_o.

(25) a. Will the volume of the cylinder increase or decrease? Explain your answer using molecular concepts.

(20) b. What is the new steady temperature of the gas?

(90) c. Find an expression for the volume of the cylinder as a function of time, t, involving only the parameters V_o, $\underline{U}$, A, T_a, T_o, n_o, and $\tilde{C}_p$. n_o is the initial

number of gas moles, and $\tilde{C}_p$ is the constant molar heat capacity of the gas at constant pressure.

(30) d. What is the time constant of the system in terms of the above parameters?

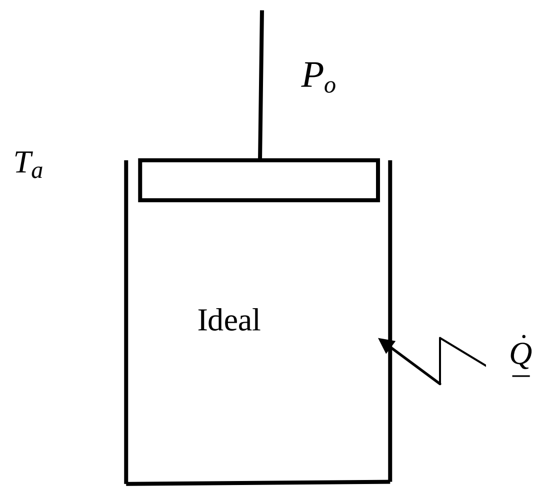

Figure 2 Heating of an Ideal Gas at Constant Pressure.

(150) 3. Short answer

(20) a. Give the expression for the isothermal, sensible change of molar enthalpy from pressure P_1 to pressure P_2 for a gas that obeys Amagat's equation of state: $P(\tilde{V}-b)=RT$ where $\tilde{V}$ is the molar volume, T is temperature, and b is a known constant that corrects for molecular finite size. Explain the physical reason underlying your answer.

(20) b. For the hydrazine reaction in Problem 1, find the standard heat of reaction at 100 °C.

(25) c. 1 kg of saturated steam at atmospheric pressure is condensed to a saturated liquid. The resulting latent heat is used to heat 1 kg of liquid water at atmospheric pressure, which was initially at 0 °C. What are the final temperatures of each stream?

(20) d. Physically, work is defined as the product of force multiplied by distance. However, a helicopter uses fuel simply to hover stationary. Using an energy balance, explain why fuel is necessary for this.

(30) e. Given below is a P-V diagram for water. Qualitatively sketch the P-T diagram for water. Draw the boundaries between the phases, label the phases, and label all numbered points from the P-V diagram on your P-T diagram.

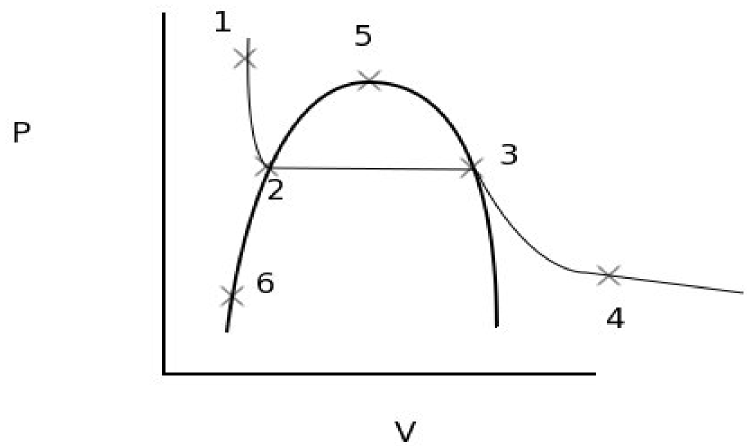

Figure 3e: A P-V diagram for water

(15) f. Explain why counter-current flow in a heat exchanger is usually better than co-current flow.

(10) g. Two experiments are run to find the adiabatic flame temperature for combustion of methane. In the first, the stoichiometric amount of oxygen is added. In the second, 50% excess oxygen is added. Assume that methane combusts completely in both cases. Which experiment has the higher adiabatic flame temperature and why?

(10) h. In the unsteady isothermal filling of a tank, the volumetric flow rate into the tank is directly proportional to the difference between the line pressure and the tank pressure to the 5/3 power. What is the expression for the volumetric flow rate into the tank?