CHE 205 — Chemical Process Principles **Fall 2005 — Section 1**

Final Examination. Open book–closed notes. Put your name, Section 1, and "Final Exam" on the outside of your blue book. Any work on the back of a page will not be considered scratch work and will not be graded. *Begin each numbered problem on a new page, show all your work, and box your final answers*.

1. (12) The following are *short* answer questions. You should not spend more than about three minutes answering each one.

(a) (2) A calculation you are doing requires evaluating $(3.513)(1.51\text{x}10^4)/5.3$. Your calculator returns a value of 9905.07519. How would you report this value using scientific notation? (Pay attention to significant figures.)

(b) (3) An inscribed copper block which is 25.0 cm x 36.0 cm x 1.00 cm is placed on the surface of the moon, where the acceleration of gravity is one sixth of its value at sea level on earth. What is the weight of the block, $W(\text{lb}_f)$? (Try to use just one dimensional equation.)

(c) (3) When water that has been standing in an open container at 20°C is heated to 30°C and held at that temperature, small bubbles form and emerge, and eventually stop forming. If the water is then heated to 40°C and held, more small bubbles emerge. Briefly explain (i) what the bubbles are, (ii) the behavior described, and (iii) what you would need to know to estimate the total amount of gas that escapes during the first stage of heating (from 20° to 30°).

(d) (4) The weather report announces that the temperature is 70°F and the relative humidity is 20%. Suppose you collect outside air containing 10 lb_m of dry air and cool it at constant pressure. (i) At what temperature ($^{\circ}$F) would water start to condense? (ii) If you cooled the air to a low enough temperature to condense essentially all of the water vapor in it, how much (lb_m) would you condense? (Use the psychrometric chart.)

2. (8) The volumetric flow rate of a gas stream entering a process at 300K and 35 atm is measured, and a mechanical engineer uses the ideal gas equation of state to calculate that the molar flow rate of the stream is 162 mol/s. You question the validity of the assumption of ideality, pull out your 205 text, find that the critical temperature and pressure of the gas are 300K and 70 atm, and recalculate the molar flow rate to get a more accurate value. What is that value?

3. (10) A gas stream containing 60.0 mole% ethanol (C_2H_5OH, normal boiling point $T_{bp} = 78.5^{\circ}$C) and the balance *n*-propanol (C_3H_7OH, $T_{bp} = 97.0^{\circ}$C) flows through a horizontal 5-cm ID pipe at a steady-state rate of 50.0 mol/s. The gas stream enters the pipe at 100°C and 1 atm and is cooled at constant pressure to its dew point and beyond (so that some of the exiting fluid is a liquid).

(a) (3) State how each of the following variables would change from one end of the pipe to the other. (↑ ↓ → or can't tell):

(i) $\dot{m}$(g/s) (ii) $\dot{V}$(L/s) (iii) gas velocity, u(m/s) (iv) $\dot{E}_k$(kJ/s) (v) $\dot{E}_p$(kJ/s) (vi) $\hat{U}$(kJ/mol)

(vii) $\hat{H}$(kJ/mol) (viii) y_E (mole fraction of ethanol in the vapor phase)

(b) (3) Without doing any calculations, what can you say about the temperature at which condensation first occurs and the mole fraction of ethanol in the first drop that forms? (Give values if possible, otherwise put upper and/or lower bounds on the values of T and x_E at the onset of condensation.)

(c) (4) Next suppose that the cooling of Part (b) proceeds far enough for essentially all of the ethanol and propanol to be condensed. Calculate the volumetric flow rate of the liquid stream (cm^3/s). *State any assumptions you make.*

4. (8) Water flowing at a rate of 100.0 kg/min at 50°C and 5 bars is heated at constant pressure to 300°C. What are the initial and final phases of the water (liquid or vapor), and at what rate (kW) must heat be supplied? *State all assumptions*.

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5. (7) The standard heat of a reaction 2A(g) + B(l) → C(g) is $\Delta\hat{H}_r^o = -500.0$ kJ/mol. Suppose 4 mol A and 4 mol B react completely in a closed rigid container that starts and ends at 25°C. (i) Calculate the extent of reaction (mol). (ii) Write and simplify the energy balance for this batch process, and use it to determine how much heat must be transferred to or from the reactor. (State which it is).

6. (55) Gaseous *n*-pentane is fed to a heated continuous steady-state reactor at 50°C and 1 atm and dehydrogenated to form 1–pentene (that's a one, not an L) in the gas-phase reaction

$$n\text{–}C_5H_{12}(g) \rightarrow 1\text{–}C_5H_{10}(g) + H_2(g)$$

A fractional conversion of 20% is obtained. The product stream emerges from the reactor at 300°C and 1 atm and is fed to a condenser. Liquid and vapor product streams emerge from the condenser in equilibrium at 25°C and 1 atm, with no hydrogen in the liquid. You wish to determine, for a basis of 100 mol C_5H_{12} fed, *the required rate of heat transfer to or from the reactor* [Q_r(kJ)], *the required rate of heat transfer to or from the condenser* [Q_c(kJ)], the *total moles of the liquid and vapor product streams leaving the condenser* [n_V and n_L], and the *volume of the vapor product* [V_V(L)].

(a) (5) Draw and fully label a flow chart of the process. Include the basis of calculation and all of the requested quantities in your labeling.

(b) (5) Do degree-of-freedom analyses on both process units to demonstrate that you have enough information to determine all of the requested quantities, basing the reactor analysis on the extent of reaction method. Assume that you have all of the necessary physical property data for the three reactive species, and that all of the unknown variables in the first unit have been determined when you do the analysis for the second unit.

(c) (5) Determine (i) the moles of each species in the reactor product stream, (ii) the extent of reaction, ξ(mol), and (iii) the standard heat of the reaction, $\Delta\hat{H}_r^o$ (kJ/mol).

(d) (15) Assume reference states for the reactor analysis, presuming that you will use the heat of *reaction* method for the energy balance, and prepare an inlet-outlet enthalpy table. Cross out unneeded cells, enter all known molar amounts [or labels from the flow chart for molar amounts if you could not do Part (c)], and label unknown specific enthalpies. Then write all of the equations you would need to determine Q_r, including equations for all labeled enthalpies. Substitute values and formulas from the text for all physical properties but heat capacities and vapor pressures, for which you should simply insert $(C_p)_{\text{species(phase)}}$ and $(p^*)_{\text{species}}(T)$ — for example, $(C_p)_{C_5H_{12}(v)}$ and $p^*_{C_5H_{12}}(25^\circ C)$.

(e) (20) Repeat (d) for the condenser analysis, taking as references for the enthalpy table the three reactive species *as gases* at 25°C and writing and labeling the equations you would need to determine the remaining quantities requested in the problem statement (including the vapor product volume). *Note:* The heat of vaporization of 1–pentene at its normal boiling point is 25.2 kJ/mol.

(f) (5) List at least five assumptions you made in the course of the calculations.

HONOR PLEDGE: "I have neither given nor received unauthorized aid on this test."

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Student Signature