Chemical Engineering 140 **April 10, 2019**

Midterm Examination #2

(115) 1. Production of a Volatile Product

Reactants X and Y are fed to a plant in a ratio of X:Y 1:2. An inert, species I, is associated with reactant X, and is fed in a ratio I:X 1:20. Total flowrate into the steady reactor is 100 lbmol/h. Stoichiometry of the reaction is X + 2Y ↔ Z. The single-pass conversion of species X is 0.3. After leaving the reactor, the product stream, including unreacted X and Y, is fed to a condenser that operates at -5°C. The liquid stream leaving the condenser is pure Z, but some Z vaporizes into the overhead gas stream exiting the condenser. Both the reactor and condenser operate at 300 bar. The vapor pressure of Z obeys the Antoine equation, $\log_{10} P^* = A - B/(C+T)$, where *A, B,* and *C* are Antoine coefficients for species *Z* and are listed in Table 1.

Table 1: Antoine parameters for Z: pressure in bar, temperature in K.

	A	*B*	*C*
Z	3.187	506.713	-80.78

(15) a. Construct a process flow diagram of the reactor/condenser plant, labeling all species present in each stream. Fill out the diagram with all specified information given in the problem statement. $32.79 - F_{X_1} = 0.3 \cdot 32.79$

(75) b. Calculate the molar flow rates of each species in every stream. How much Z is produced in the liquid product stream in one year assuming continuous operation?

(10) c. Environmental regulations require that no more than 1 mole of Z be released per day. How much must be scrubbed from the purge stream per hour before it is considered environmentally safe?

(15) d. Every week, the scrubbed *Z* is fed to an initially empty evacuated tank (zero absolute pressure) with a volume of 100 L at ambient temperature (25°C). What is the pressure in the tank at the end of the week? Assume that species *Z* obeys the van der Waals equation of state:

$$P = \frac{RT}{V_m - b} - \frac{a}{V_m^2}$$

where V_m is the molar volume, a = 4.225 L^{2}bar/mol^2 and b = 0.0371 L/mol.

(125) 2. Plug-Flow Reactors in Series

In a plug-flow reactor, species *A* undergoes a reversible, elementary, isomerization reaction, $A \leftrightarrow B$, over a supported metal catalyst. *A* and *B* are liquid miscible and of equivalent density. The equilibrium constant for the reaction (in concentration units) is 5.8. With pure *A* feed (at concentration C_{A0}), the net conversion is 55 %. C_A –

(25) a. Write the expression for the reaction rate in terms of concentration of *A*, the reverse reaction constant k_{-1}, and the equilibrium constant *K*.

(25) b. Write the differential design equation for the reactor in terms of concentration of *A*, reactor volume *V*, and volumetric flow rate, *Q*. Substitute the rate expression from part a.

(35) c. Solve the design differential equation, list the boundary condition, and express the result in terms of conversion.

(15) d. Obtain the value of the ratio of reactor residence time to the characteristic reaction time: $\tau \equiv k_{-1}(1+K)V/Q$.

(25) e. If a second identical plug-flow reactor is connected in series, what is the conversion from the second reactor? Remember, inlet conversion to the second reactor is that from the first reactor. Thus, return to the design differential equation in part c and impose the initial condition $X(V=0)=X_o$ where X_o is the inlet conversion to the second reactor coming from the first reactor.