NATIONAL EXAMINATIONS - DECEMBER 2002

98-CHEM-A4, Chemical Reactor Engineering

Duration: 3 hours

NOTES:

1. If you have any doubt as to the interpretation of a question, please submit with your answer a clear statement of any assumptions you make, if possible, underlined or enclosed in a box.

2. OPEN BOOK EXAM

   a non-communicating, programmable electronic calculator including a small operating guide. Please indicate the name and model of your calculator on the first inside left-hand sheet of the exam work book.

3. Graph paper will be provided.

4. Any **FOUR** questions constitute a complete paper and, unless you indicate otherwise, only the first four answers will be marked.

5. Technical content is the key factor in your answers. It is essential, however, that you express yourself clearly: the examiner will not interpret remarks that are unclear.

6. Each question is worth 20 marks. Marking schemes are indicated by the numbers in brackets such as "{5 marks}" following each part of a problem.

a) It would help the examiner if you would cite the origin of significant formulas used - e.g., Fogler, eq. (3-44)

b) Please treat all the data provided as exact and give your answers to three significant figures.

1. A second-order, homogeneous, liquid-phase reaction occurs in a CSTR: **A → B.** The reaction is exothermic. We may assume that the CSTR operates adiabatically. Data are as follows and should be considered as exact quantities:

τ = 1100 s (Residence time of the liquid in the CSTR)
ρ = 800 g/L (Liquid density; the reaction to B does not alter this density significantly.)
ΔH_r = -30 000 J/mol$_A$ (Enthalpy of reaction; this may be considered constant in the range of temperature of this problem.)
$(-r_A) = 2.0(10^{13})e^{(-83860/RT)}C_A$ (The rate of reaction in units [mol$_A$/L·s]; where R = 8.314 [J/mol·K]; T is in [K]).
$C_A°$ = 1.5 mol$_A$/L (Inlet concentration of A)
C_p = 3.5 J/g·K (The heat capacity of the reacting fluid; this quantity is assumed not to vary with the extent of reaction. We shall also assume that the heat capacity of the vessel and stirrer is insignificant.)
T° = 400 K (Inlet temperature of feed)
V = 600 L (Reactor volume)

a) What are the units of the constant $2.0(10^{13})$ in the rate equation? {2 marks}
b) Show by appropriate calculations that this reactor operates at 325.7 K under steady state operating conditions. {10 marks}
c) What is the conversion of A at the operating temperature? {4 marks}
d) Calculate the rate of heat evolved within this reactor (in J/s) during steady-state operation. {4 marks}

2. A gas-phase, isothermal, irreversible, second-order reaction of the form

$$A + B \rightarrow C$$

is carried out in an isothermal, plug-flow reactor the dimensions of which are 2.5 cm in internal diameter and 3.0 m in length. A mixture of A and B that is 50 mol% in both reactants is fed to the reactor at a rate of 0.75 mol/h A and 0.75 mol/h of B at 300°C and 101.3 kPa total pressure. The resulting conversion is 53.0%.

a) Calculate the space time (in seconds) of the reactor at 101.3 kPa entering pressure. {8 marks}

b) Calculate the rate constant of the above reaction. Hint: See Fogler's textbook (2nd ed., Chapter 4) for an integrated form of the necessary equation. {12 marks}

3: At a constant temperature of 280°C, the reaction of pure A occurs in the gas phase with the following stoichiometry:

$$A \rightarrow 2\,B$$

Total pressure data for this reaction are provided in the table below.

Time, s	Total pressure, kPa
0	2.000
500	2.520
800	2.760
1300	3.066
1800	3.306

a) Show by plotting the data to the integrated form of a second order reaction that this model does ***not*** adequately fit the data. (Graphical or tabular solutions are equally acceptable.) {6 marks}

b) Show that the data do fit a first-order rate law. {6 marks}

c) Report the mean rate constant in appropriate units. {2 marks}

d) If the rate constant at 265°C were half as large as the value reported in (c), what would be the activation energy for this process in kJ/mol? {6 marks}

4. A pair of identical CSTRs-in-series, each having a volume of 500 L, is fed by two independent liquid streams that flow into the first CSTR. One stream contains reactant A in water, the other contains reactant B in water. Reaction occurs irreversibly according to the stoichiometry $A + B \rightarrow C + D$, where C and D are water-soluble, inert products. Reactant A enters the first reactor from its feed stream at a concentration of exactly 0.01 mol/L and at a volumetric flow of 5.00 L/s; B enters the first reactor separately at a feed concentration of exactly 0.20 mol/L and at a flow of 10 L/s. The temperature of reaction is maintained at 75°C in both reactors according to a rate law $(-r_A) = kC_AC_B$, in units of mol/s where k = 0.55 L/(mol•s).

Calculate the conversion of A in the outlet stream of the first and second reactors. {20 marks}

5. In a tubular flow reactor, two liquid reactants are instantaneously mixed at the entrance and react as the mixture flows through a bed containing inert spheres. The resulting temperature within the liquid is plotted against the distance downstream as shown in Figure 1. This result, labelled "1", is a plot of the steady-state temperature along the centre-line of the reactor vs. the distance from the bed entrance for an adiabatic (perfectly insulated) reactor, starting at a feed temperature of 20°C. The reaction is first order in each reactant. Identify which situation (from "a" to "c" below) is described by a single numbered line (from "2" to "7") on the figure. You may assume that the steady-state temperature is constant across the diameter of the reactor at any axial coordinate. You may also assume that the plot is sufficiently quantitative to allow meaningful comparisons to be made.

a) A tubular reactor with external heat losses during the reaction. {3 marks}

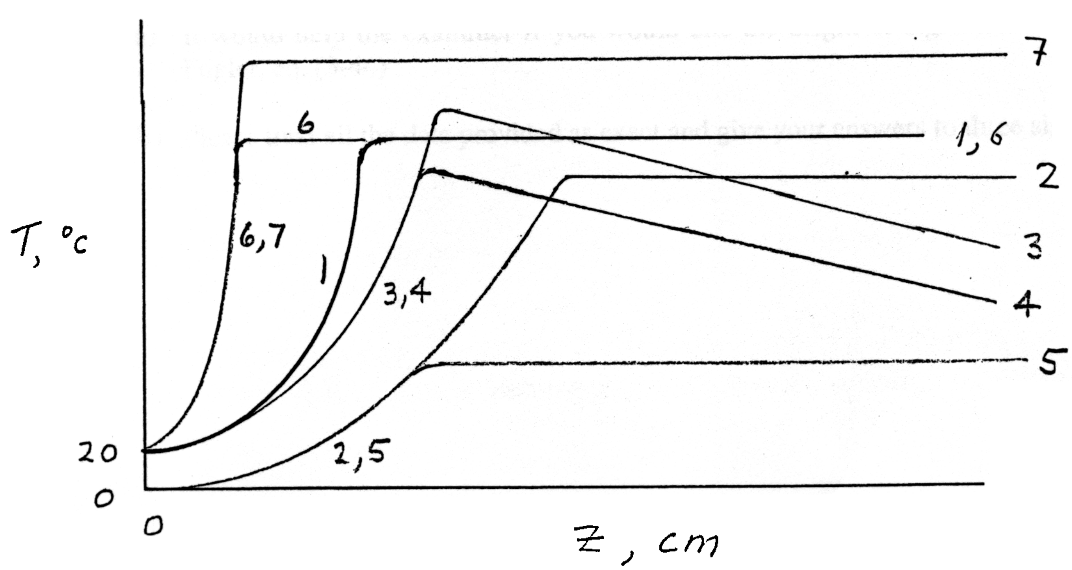
b) A tubular reactor in adiabatic operation in which the inert spheres are replaced by ones covered with catalyst capable of promoting the reaction mentioned above. {4 marks}

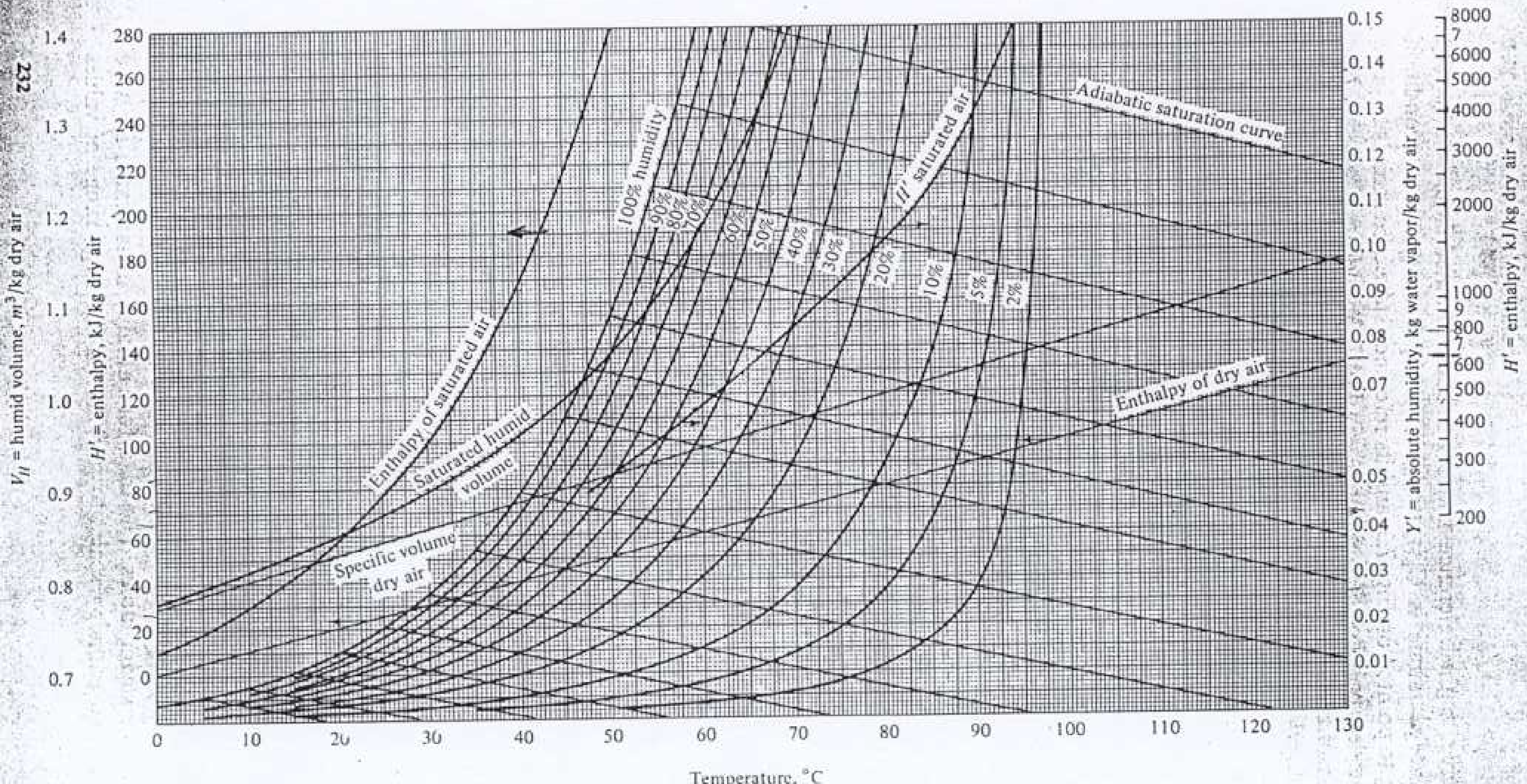
c) An adiabatic non-catalytic tubular reactor starting from 0°C. {4 marks}

d) Calculate the rate of energy (kJ/s) available from the original adiabatic reaction assuming the product were cooled to the starting temperature of 20°C. Define any quantities needed for this calculation and use compatible units. {3 marks}

e) Repeat part (d) for the addition of catalyst. {3 marks}

f) If the activation energy of this reaction is 80 kJ/mol, by what factor would the initial rate of reaction be increased at an initial temperature of 50°C for the same concentration of reactants? {3 marks}





(a)

Figure 7.5 (*a*) Psychrometric chart for air-water vapor, 1 std atm abs, in SI units.