16-CHEM-A4, CHEMICAL REACTOR ENGINEERING

DECEMBER 2017

3 hours Duration

1. If doubt exists as to the interpretation of any question, please submit with your answer a clear statement of any assumption(s) you make. If possible, please underline or enclose any such statement in a box.
2. This is an OPEN BOOK EXAM. However only the items listed below are permitted into the exam.
   - One textbook of your choice with notations listed on the margins etc but no loose notes are permitted into the exam.
   - your own unit conversion tables and/or mathematical tables such as a CRC Handbook.
   - a non-communicating, programmable electronic calculator using a small operating guide. Please write the name and model of your calculator on the first inside left-hand sheet of the exam workbook.
3. Answering any **four** questions will constitute a complete paper. Unless you indicate otherwise, only the first four answers as they appear in your answer booklet will be marked.
4. Each question is worth 25 points. Marking schemes are provided below for each question.
5. Technical content is the key ingredient in your answers. However, no credit will be given for deriving rate expressions, or standard formulas that are available in the textbook. Clear writing is essential, particularly when explanations are required.
6. It will help the examiner if you could cite the origin of significant formula used – e.g., Fogler, eq. (3-44).

Marking Scheme – Four questions comprise a complete exam.

1. 25 points – a) 10 points, b) 10 points, c) 5 points
2. 25 points – a) 18 points, b) 7 points
3. 25 points – a) 15 points, b) 5 points, c) 5 points
4. 25 points
5. 25 points

QUESTION 1

Consider the following reversible hydrodealkylation reaction of toluene to benzene and methane:

$$C_7H_8 + H_2 \leftrightarrow C_6H_6 + CH_4$$

The feed to the reactor consists of 2 moles of hydrogen per mole of toluene.

(a) For this feed ratio and an outlet temperature of 900 K, compute the equilibrium conversion based on toluene. The equilibrium constant (K_p) of the reaction at 900 K is 227.

(b) If the reactor were operated adiabatically and the products were withdrawn at equilibrium, calculate the temperature rise which would occur with this feed. For the reaction at 900 K, - ΔH = 50 MJ/Kmol.

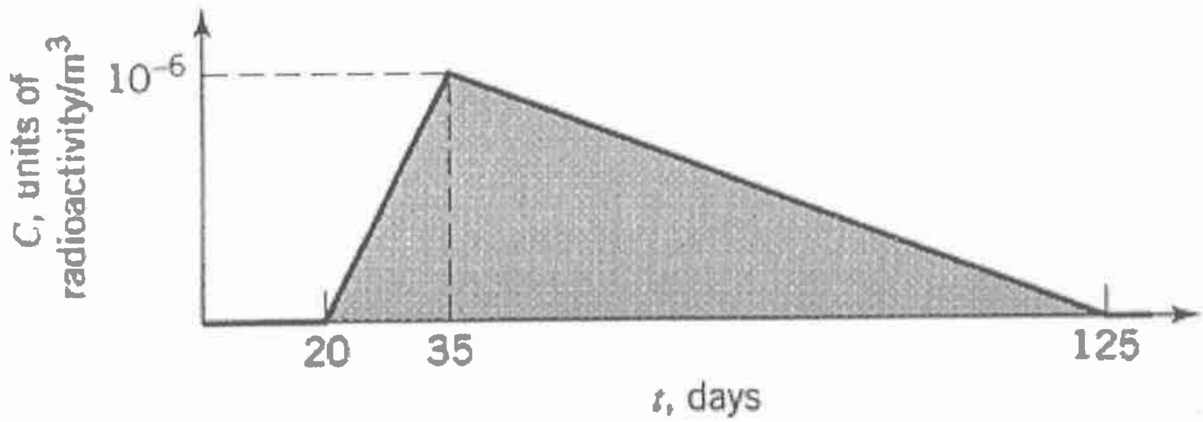
(c) If the maximum permissible temperature rise for this process is 100 K, then suggest a suitable design for the reactor.

Specific Heat Capacity Data at 900 K in KJ/Kmol:

Benzene = 198 Toluene = 240 Methane = 67 Hydrogen = 30

QUESTION 2

A batch of radioactive material is dumped into a river. At a dam about 400 kilometers downstream, the water flowing at 6000 m^3/s is monitored for a particular radioisotope that has a half-life ($t_{1/2}$) greater than 10 years and the following data was obtained:



(a) How many units of this radioactive tracer were introduced into the river?

(b) What is the volume of water between the dam and the point of introduction of radioactive tracer?

QUESTION 3

The reaction **A → R** takes place in packed bed reactor using various amounts of catalyst and a fixed feed rate of 10 Kmol/hr of A. The following data was obtained for conversion of A (X_A) for various amounts of catalyst:

Amount of Catalyst (kg)	**Conversion (X_A)**
1	0.12
2	0.20
3	0.27
4	0.33
5	0.37
6	0.41
7	0.44

(a) Find the reaction rate at 40% conversion.

(b) How much catalyst would be needed for 40% conversion if we have to design a large packed bed reactor where the feed rate of A is increased to 400 Kmol/hr?

(c) How much catalyst would be needed to design a large packed reactor with a very large recycle of product stream for 40% conversion and feed rate of 400 Kmol/hr of A?

QUESTION 4

The first order reaction **A → R** takes place in an experimental mixed flow reactor at 1 atm and 336 °C. The reactor contains 10 grams of catalyst particles (diameter = 1.2 mm) and 4 cm^3/s of pure A is fed to the reaction. There is no heat of reaction. You have to design a commercial-sized reactor to treat large amounts of feed to 80% conversion at 1 atm and 336 °C. Your choice is between a fluidized bed reactor of 1-mm particles (assume mixed flow of gas) and a packed bed reactor of 1.5-cm particles. The density of particles (ρ_s) is 2000 kg/m^3 and effective mass diffusivity coefficient (D_e) is 1 x 10^{-6} m^3/m cat.s.

Which type of reactor would you choose so as to minimize the amount of catalyst needed and how much advantage is there in this choice?

QUESTION 5

The gas-phase reaction **2A → A_2** was carried out at a temperature of 325 °C and constant volume. Measurements of the total pressure as the reaction proceeds gave the following data:

Time (min)	Total Pressure (kPa)
0	84.25
10	78.91
20	74.45
30	71.12
40	68.52
50	66.25
60	64.52
70	63.05
80	61.72

A rate equation of the form $-dP/dT = kP^n$ is assumed, where P is the partial pressure of A, k is the reaction rate constant and n is the order of the reaction.

Determine the values of k and n.