16-CHEM-A4, CHEMICAL REACTOR ENGINEERING

MAY 2018

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 in brackets after 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
2. 25 points
3. 25 points
4. 25 points
5. 25 points – a) 13 points, b) 12 points

QUESTION 1

Ethylene (C_2H_4) is manufactured on a very large scale by the thermal cracking of ethane (C_2H_6) in the gas phase given by the following reversible equation:

$$C_2H_6 \longleftrightarrow C_2H_4 + H_2$$

Ethane (molecular weight = 30) is diluted with steam in a tubular furnace and fed to an isothermal tubular/plug flow reactor, which is maintained at 900 °C. Ethane will be supplied to the reactor at a rate of 2×10^4 kg/hr and it will be diluted with steam in the ratio of 0.5 moles of steam per mole of ethane. The reactor is operated at a constant pressure of 1.4 bar (1.4×10^5 Pa). Laboratory experiments show that ethane decomposition is a homogeneous first-order reaction and the rate constant **k** at 900 °C is 12.8 sec^{-1}. Determine the volume of reactor necessary to convert 60% of ethane to ethylene.

QUESTION 2

Gaseous reaction **A → R** is carried out in a heterogeneous plug flow reactor at a volumetric flow rate of 3 L/min and C_{A0} = 60 moles/m^3, and the following conversion data at various conditions were obtained:

Amount of Catalyst (gm)	Concentration of A (moles/m^3)
0.5	30
1.0	20
2.5	10

Find a rate expression to represent the reaction.

QUESTION 3

The pyrolysis of a material **A** (molecular weight = 146) at temperature near 500 °C was studied at various pressures. The reaction is represented by the gas-phase equation **A → B + C**. Below 565 °C, the pyrolysis reaction is first order with a rate constant **k** (in sec^{-1}) as a function of temperature **T** (in K) is given by the equation

$$k = 7.8 \times 10^{9}\, e^{-19220/T}$$

It is desirable to design a pilot scale tubular/plug flow reactor (6 inches in diameter and $3.88 \times 10^{-2}\ ft^2$ in area) to operate isothermally at 500 °C. The feedstock enters the reactor at 5 atm and a flow rate of 500 lb/hr. Assuming ideal gas behavior and negligible pressure drop across the reactor, what is the length of the reactor required to convert 90% of material A to product C?

QUESTION 4

Reagent A undergoes an irreversible first-order reaction **A → B**, and both A and B are liquids at room temperature and have extremely high boiling points. The rate constant **k** (in hr^{-1}) as a function of temperature **T** (in K) is given by the equation

$$k = 2.61 \times 10^{14}\, e^{-14570/T}$$

How much of the product B will it be possible to produce from 2.1×10^6 lb/year of reactant A using two 1000-gallon mixed flow/continuous stirred tank reactors operating in series under adiabatic conditions and for 7000 hr/year? The feed to the first reactor is at 20 °C.

DATA:

Density of A = 7.5 lb/gal

Heat of reaction = -83 cal/g

Specific heat capacity of A and B = 0.5 cal/g °C

QUESTION 5

A solution containing 0.5 lb mol/ft^3 of reactive component A is to be treated at the rate of 25 ft^3/hr. The reaction rate equation (in lb mol/ft^3.hr) is given by

$$r_A = -dC_A/dt = 2.33\ C_A^{1.7}$$

(a) If the downtime is 45 minutes per batch, what size of batch reactor is needed for 90% conversion?

(b) If the batch reactor is replaced by two-stage mixed flow/continuous stirred tank reactor with each reactor being 50 ft^3, what is the conversion of A at the end of each stage?