

CHEMICAL REACTOR DESIGN

CHENG 323

Dr Shaker Haji

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Lecture 34

(Week 9)

Prepared by: Dr Shaker Haji - CHENG 323

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6 Multiple Reactions

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In this Chapter

- Seldom is the rxn of interest the only one that occurs *in a* chemical reactor.
- Typically, multiple rxns will occur, some desired & some undesired.
- One of the key factors in the economic success of a chemical plant is the minimization of undesired side rxns that occur along with the desired rxn.
- In this chapter, we will introduce the topic of multiple reactions.
- We describe the four basic types of multiple reactions: series, parallel, independent, and complex.
- Next, we define the selectivity parameter and discuss how it can be used to minimize unwanted side reactions.
- We will also discuss the yield.

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6.1 Definitions

6.1.1 Types of Multiple Reactions

Series Reactions:

- Also called consecutive reactions.
- They are rxns where the reactant forms an intermediate product, which reacts further to form another product:

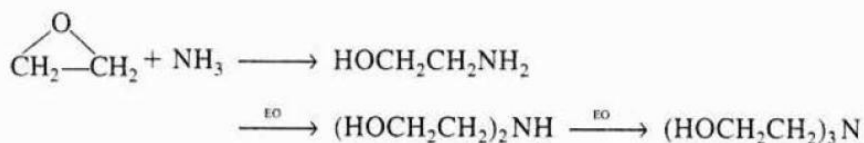


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6.1.1 Types of Multiple Reactions

Series Reactions:

- Example: the rxn of ethylene oxide (EO) with ammonia to form mono-, di-, and tri-ethanolamine:



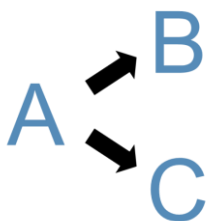
- In recent years the shift has been toward the production of diethanolamine as the desired product rather than triethanolamine.

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6.1.1 Types of Multiple Reactions

Parallel Reactions:

- Also called competing reactions.
- They are rxns where the reactant is consumed by two different reaction pathways to form different products:



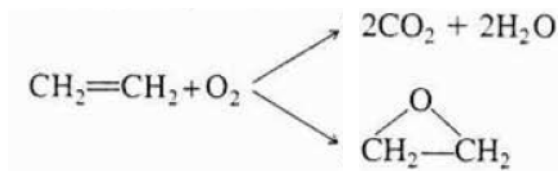
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6.1.1 Types of Multiple Reactions

Parallel Reactions:

- Example:

the oxidation of ethylene to ethylene oxide while avoiding complete combustion to CO_2 & H_2O .

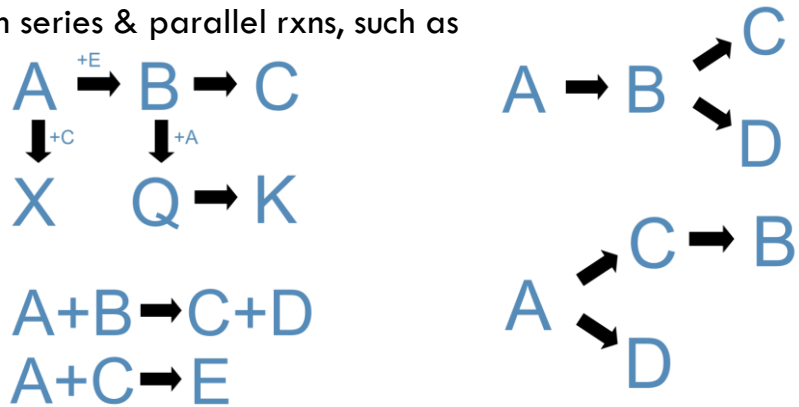


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6.1.1 Types of Multiple Reactions

Complex Reactions:

- They are multiple reactions that involve a combination of both series & parallel rxns, such as

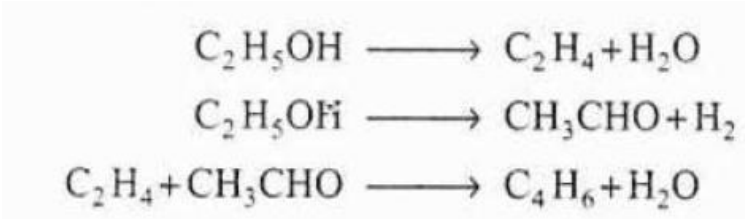


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6.1.1 Types of Multiple Reactions

Complex Reactions:

- Example: the formation of butadiene from ethanol

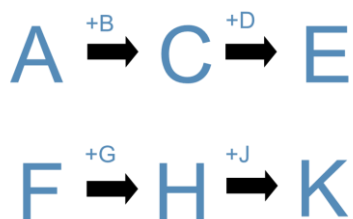


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6.1.1 Types of Multiple Reactions

Independent Reactions:

- They are reactions that occur at the same time but neither the products nor reactants react with themselves or one another.

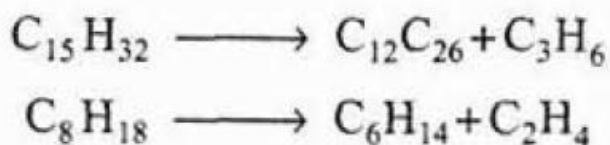


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6.1.1 Types of Multiple Reactions

Independent Reactions:

- Example: the cracking of crude oil to form gasoline where two of the many reactions occurring are



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Are these Complex Reactions? (D is your desired product)

A+B→C+D

A+C→E

Are these Series, Parallel or Complex Reactions?

(E is your desired product and A can be provided in excess)

A+B→C

A+C→E

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Are these Complex Reactions? (D is your desired product)

A+B→C+D

A+C→E

Are these Series, Parallel or Complex Reactions?

(E is your desired product and A can be provided in excess)

A+B→C

A+C→E

=

B

^{+A}

→

C

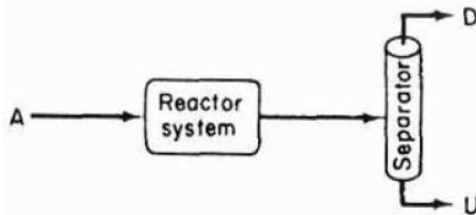
^{+A}

→

E

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Sophisticated vs. Inexpensive Reactors

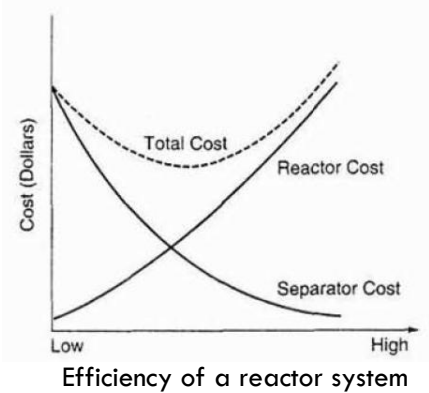


Reaction-separation system producing both desired and undesired products.

- We want to minimize the formation of U & maximize the formation of D, because the greater the amount of U formed, the greater the cost of separating the U from D.

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Sophisticated vs. Inexpensive Reactors



- Normally, as the cost of a reactor system increases in an attempt to minimize U, the cost of separating species U from D decreases.

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6.1.2 Figures of Merit



□ A **Figure of Merit** is a quantity used to characterize the performance of a device, system or method, relative to its alternatives.

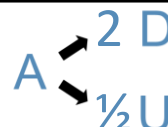
□ **Figures of merit for CRE:**

we can quantify the formation of D with respect to U by defining the selectivity and yield of the system:

- **Selectivity:** tells us how one product is favored over another when we have multiple reactions.
- **Yield:** tells us how much useful conversion is achieved.

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Selectivity & Yield



□ From the “Introduction to Chemical Engineering” Course:

$$\text{Selectivity} = \frac{\text{moles of desired product formed}}{\text{moles of undesired product formed}}$$

$$\text{Yield (fractional)} = \frac{\text{moles of desired product formed}}{\text{moles would have been formed if: no side rxns \& X=100\%}}$$

$$\text{Yield (fractional)} = \frac{\text{moles of desired product formed}}{\text{moles would have been formed for the given X when no side rxns}}$$

$$\text{Yield} = \frac{\text{moles of desired product formed}}{\text{moles of reactant fed}}$$

$$\text{Yield} = \frac{\text{moles of desired product formed}}{\text{moles of reactant consumed in the reactor}}$$

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Selectivity & Yield

$A \rightarrow D \rightarrow U$

$A \begin{cases} \rightarrow D \\ \rightarrow U \end{cases}$

□ Selectivity & yield can be based on the ratio of reaction rates (instantaneous) or on the ratio of molar flow rates (overall)

Instantaneous

Overall

Selectivity

Yield

$S_{D/U} = \frac{r_D}{r_U}$

$\tilde{S}_{D/U} = \frac{F_D - F_{D0}}{F_U - F_{U0}}, \tilde{S}_{D/U} = \frac{N_D - N_{D0}}{N_U - N_{U0}}$

$Y_D = \frac{r_D}{-r_A}$

$\tilde{Y}_D = \frac{F_D - F_{D0}}{F_{A0} - F_A}, \tilde{Y}_D = \frac{N_D - N_{D0}}{N_{A0} - N_A}$

where A is the key reactant, D is the desired product, & U is the undesired product.

□ For CSTR, the instantaneous and overall values are the same (Prove it).

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Selectivity & Yield

$\tilde{S}_{D/U} = \frac{F_D - F_{D0}}{F_U - F_{U0}} \qquad \tilde{Y}_D = \frac{F_D - F_{D0}}{F_{A0} - F_A}$

□ If F_{D0} & F_{U0} are zero, then:

$S_{D/U} = \frac{r_D}{r_U}$

$Y_D = \frac{r_D}{-r_A}$

$\tilde{S}_{D/U} = \frac{F_D}{F_U}$

$\tilde{Y}_D = \frac{F_D}{F_{A0} - F_A}$

$S_{D/U} = \frac{r_{D,net}}{r_{U,net}} = \frac{\text{net rate of formation of desired product D}}{\text{net rate of formation of undesired product U}}$

$Y_D = \frac{r_{D,net}}{-r_{A,net}} = \frac{\text{net rate of formation of product D}}{\text{net rate of consumption of the key reactant A}}$

$\tilde{S}_{D/U} = \frac{F_D}{F_U} = \frac{\text{exit molar flow rate of desired product D}}{\text{exit molar flow rate of undesired product U}}$

$\tilde{Y}_D = \frac{F_D}{F_{A0} - F_A} = \frac{\text{moles of desired product D formed}}{\text{moles of the key reactant A consumed}}$

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Selectivity & Yield

$A \rightarrow D \rightarrow U$

$A \begin{cases} \rightarrow D \\ \rightarrow U \end{cases}$

$S_{D/U} = \frac{r_D}{r_U}$

$Y_D = \frac{r_D}{-r_A}$

$\tilde{S}_{D/U} = \frac{F_D}{F_U}$

$\tilde{Y}_D = \frac{F_D}{F_{A0} - F_A}$

- From an economic standpoint, the overall selectivities & yields are important in determining profits.
- However, instantaneous selectivities give insights in choosing reactors and reaction schemes that will help maximize the profit.
- There often is a conflict between selectivity and conversion because you want to make a lot of your desired product (D) and at the same time minimize the undesired product (U).
- However, in many instances, the greater X you achieve, not only do you make more D, but you also form more U.

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6.2 Maximizing the Desired Product in Parallel Reactions



6.2.1 Maximizing the Desired Product

- In this section, we discuss means of maximizing the desired product, D, through the selection of reactor *type* and *conditions*.
- Consider the following parallel rxns:

$$\begin{array}{lcl} A & \xrightarrow{k_D} & D \quad (\text{desired}) \\ A & \xrightarrow{k_U} & U \quad (\text{undesired}) \end{array}$$
- The rate laws are: $r_D = k_D C_A^{\alpha_1}$ & $r_U = k_U C_A^{\alpha_2}$
- The net rate of disappearance of A is:

$$-r_A = k_D C_A^{\alpha_1} + k_U C_A^{\alpha_2}$$

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$$-r_A = k_D C_A^{\alpha_1} + k_U C_A^{\alpha_2} \qquad r_D = k_D C_A^{\alpha_1} \qquad r_U = k_U C_A^{\alpha_2}$$

- We should examine ways to maximize the instantaneous selectivity, $S_{D/U}$, for different reactions (different orders & different activation energies)
- The instantaneous selectivity which is to be maximized:
$$S_{D/U} = \frac{r_D}{r_U} = \frac{k_D}{k_U} C_A^{\alpha_1 - \alpha_2}$$
- The sensitivity of the instantaneous selectivity to T can be determined from the ratio of reaction constants, k_D/k_U
$$S_{D/U} \sim \frac{k_D}{k_U} = \frac{A_D}{A_U} e^{-[(E_D - E_U)/RT]}$$

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$$\begin{array}{l} A \xrightarrow{k_D} D \\ A \xrightarrow{k_U} U \end{array}$$

$$S_{D/U} = \frac{r_D}{r_U} = \frac{k_D}{k_U} C_A^{\alpha_1 - \alpha_2}$$

$$S_{D/U} \sim \frac{k_D}{k_U} = \frac{A_D}{A_U} e^{-[(E_D - E_U)/RT]}$$

- Case 1: $\alpha_1 > \alpha_2$, $S_{D/U} = \frac{r_D}{r_U} = \frac{k_D}{k_U} C_A^a$ where a is +ve no.

Conditions:	High C_A :- Gas: w/o inert, high P . Liquid: no diluent.
Reactors:	Preferred: Batch, PFR. Avoid: CSTR

- Case 2: $\alpha_2 > \alpha_1$, $S_{D/U} = \frac{r_D}{r_U} = \frac{k_D}{k_U C_A^b}$ where b is +ve no.

Conditions:	Low C_A :- Gas: use inert, low P . Liquid: use diluent.
Reactors:	Preferred: CSTR & recycle reactor.

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$$\begin{array}{l} A \xrightarrow{k_D} D \\ A \xrightarrow{k_U} U \end{array}$$

$$S_{D/U} = \frac{r_D}{r_U} = \frac{k_D}{k_U} C_A^{\alpha_1 - \alpha_2}$$

$$S_{D/U} \sim \frac{k_D}{k_U} = \frac{A_D}{A_U} e^{-[(E_D - E_U)/RT]}$$

Case 3: $E_D > E_U$, $k_{D/U} = (A_D/A_U)/(e^{a/T})$ where a is +ve no.

Conditions:

Reasonably High T .

Reactors:

Why high T ?!

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Comments on Arrhenius Equations

$$k_A(T) = Ae^{-E/RT}$$

There is a rule of thumb that states that the rate of reaction doubles for every increase of 10°C in temperature.

However, this is true only for a specific combination of E_a & T .

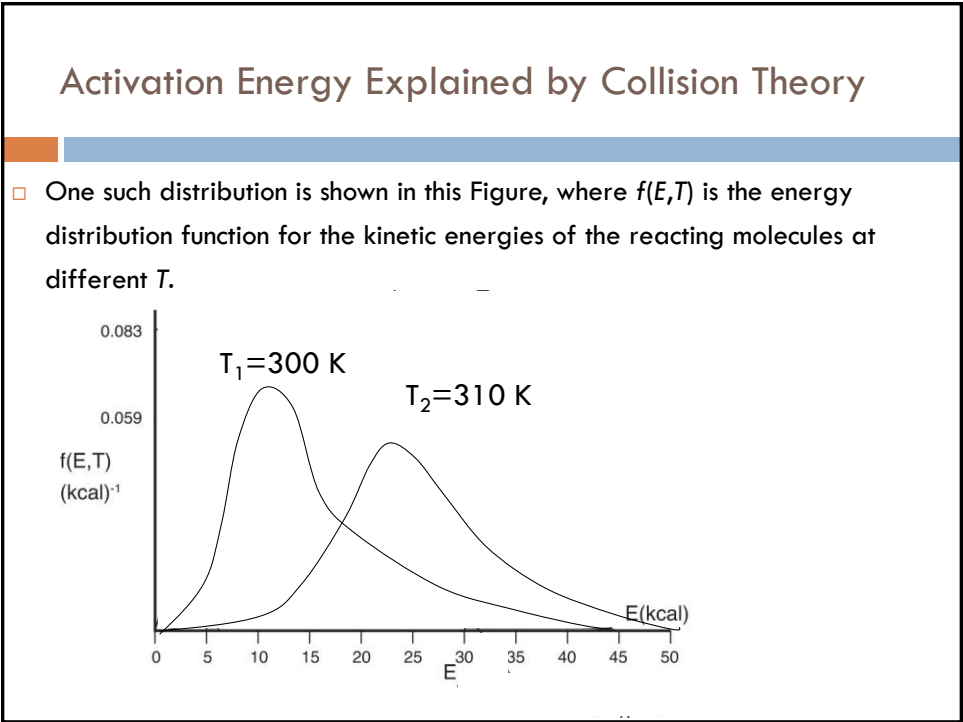
For example, if $E_a = 55$ kJ/mol, the rate will double only if T is raised from 300 K to 310 K.

If the $E_a = 150$ kJ/mol, the rule will be valid only if the T is raised from 500 K to 510 K.

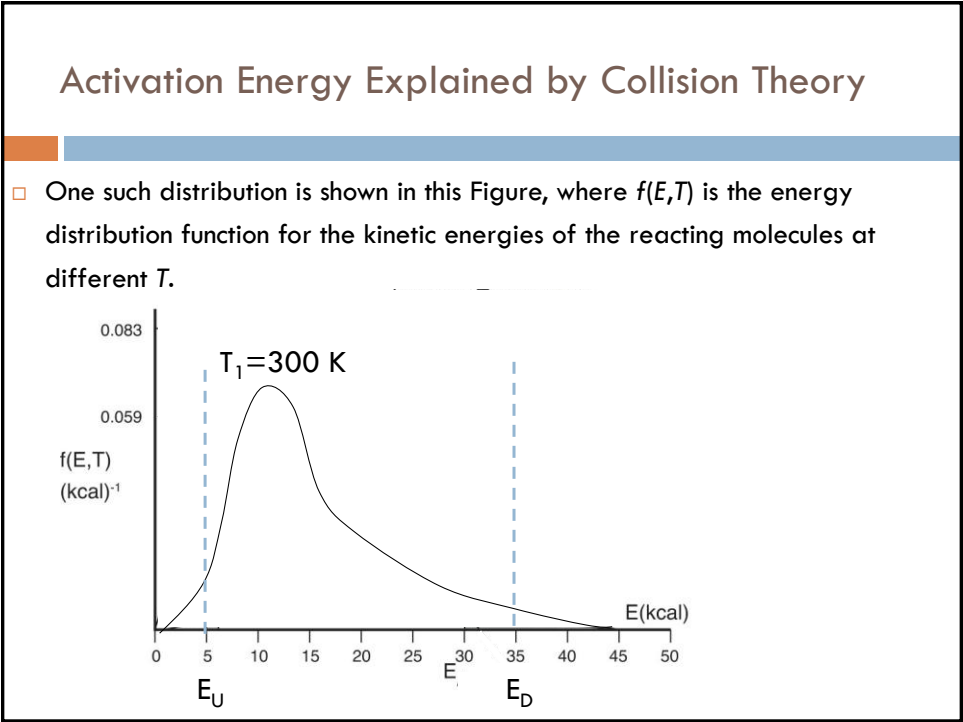
The larger the E_a , the more temperature-sensitive is the rate of reaction.

E_a , kJ/mol	k_{310}/k_{300}
55	2.0
107	4.0
150	7.0
200	13.3

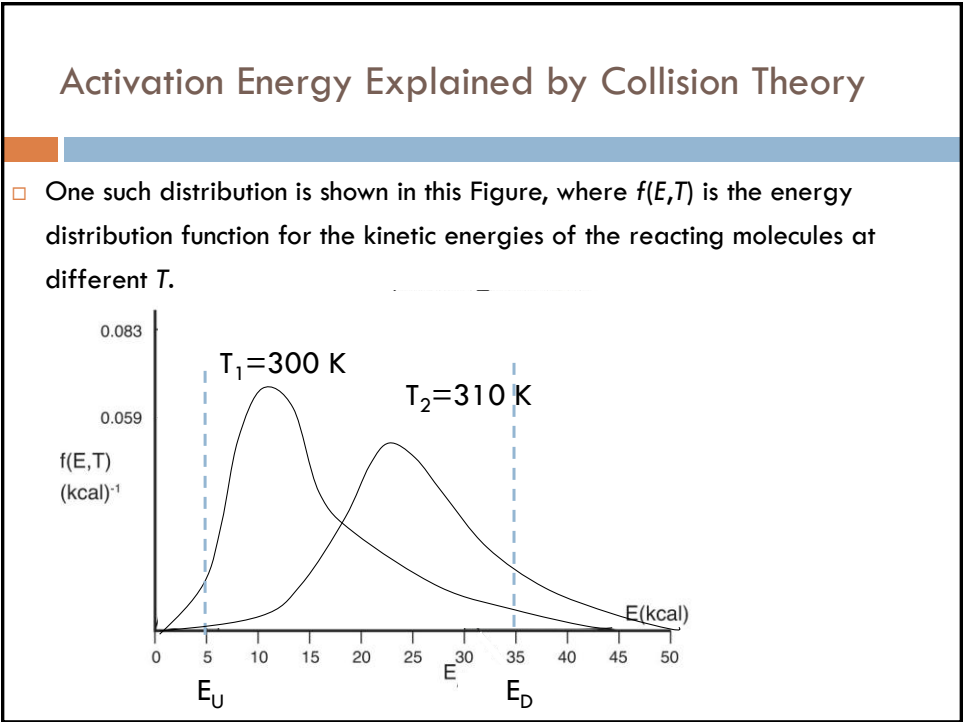
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$$\begin{array}{l} A \xrightarrow{k_D} D \\ A \xrightarrow{k_U} U \end{array}$$
$$S_{D/U} = \frac{r_D}{r_U} = \frac{k_D}{k_U} C_A^{\alpha_1 - \alpha_2}$$
$$S_{D/U} \sim \frac{k_D}{k_U} = \frac{A_D}{A_U} e^{-[(E_D - E_U)/RT]}$$

One such distribution is shown in this Figure, where $f(E,T)$ is the energy distribution function for the kinetic energies of the reacting molecules at different T .

Case 3: $E_D > E_U$, $k_{D/U} = (A_D/A_U)/(e^{a/T})$ where a is +ve no.

Conditions:

Reasonably High T .

Reactors:

Heated Reactor, Heated Feed (Heat Exchangers)

Case 4: $E_U > E_D$, $k_{D/U} = (A_D/A_U)*(e^{b/T})$ where b is +ve no.

Conditions:

Reasonably Low T .

Reactors:

Cooled Reactor, Cooled Feed (Heat Exchangers)

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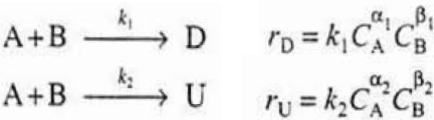
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6.2.2 Reactor Selection and operating Conditions



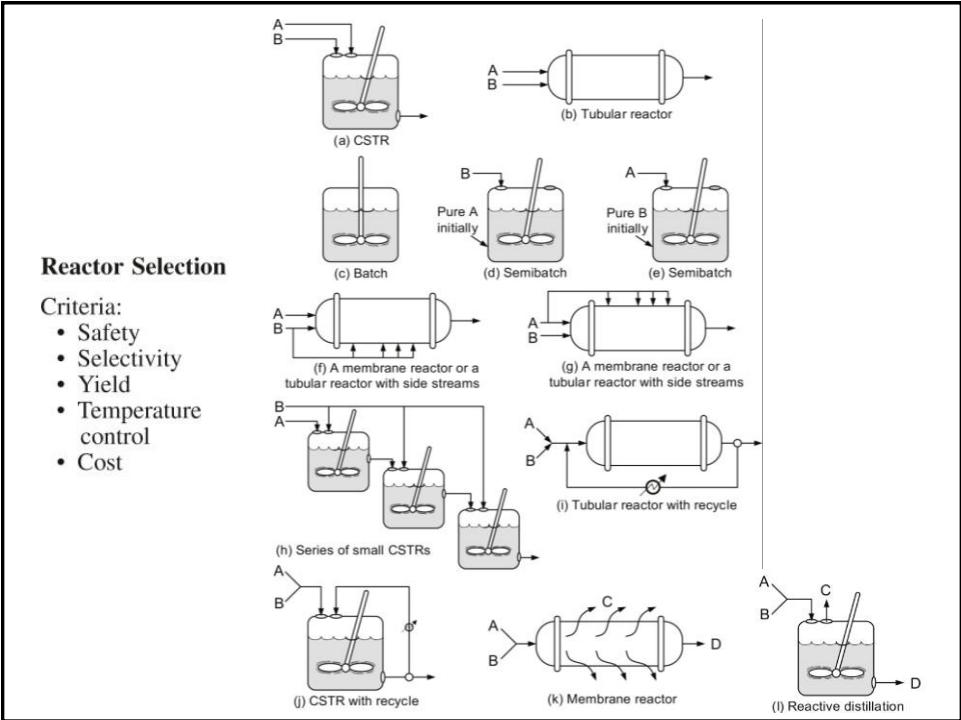
consider the following two simultaneous reactions:



$$S_{D/U} = \frac{r_D}{r_U} = \frac{k_1}{k_2} C_A^{\alpha_1 - \alpha_2} C_B^{\beta_1 - \beta_2}$$

- The selectivity parameter has to be maximized.
- Following are various reactor schemes and conditions that might be used to maximize $S_{D/U}$.

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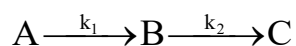
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6.3 Maximizing the Desired Product in Series Reactions

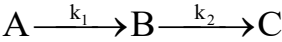
- We saw earlier that the undesired product could be minimized by adjusting the rxn conditions (e.g., T , C_A) & by choosing the proper reactor.
- For a series of consecutive rxns, the most important variable is time:
 - ▣ real-time: for a batch reactor.
 - ▣ space-time: for a flow reactor
- Consider the following consecutive reactions in which B is the desired product:



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6.3 Maximizing the Desired Product in Series Reactions

Batch Reactor:



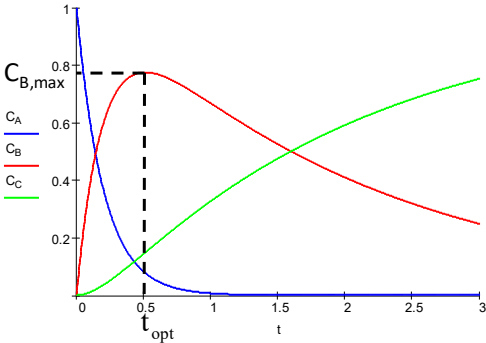
- When should we stop the rxn to obtain the maximum amount of B?

or

- Find the optimum time.

$$\left. \frac{dC_B}{dt} \right|_{t=t_{opt}} = 0$$

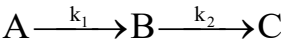
- Explain C_B 's behavior.



Courtesy of Prof. David Rockstraw, New Mexico State University.

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Continuous Flow Reactor (PFR/CSTR):



- How large should the reactor be or how fast should the volumetric flow rate be to obtain the maximum amount of B?

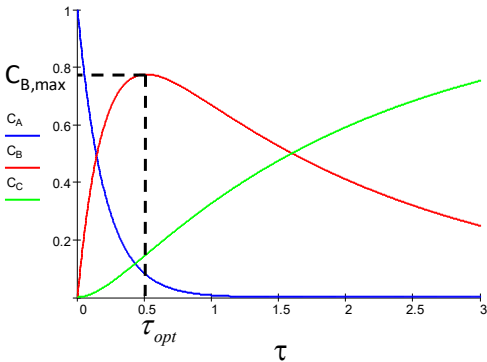
or more correctly:

- Find the optimum τ .

$$\left. \frac{dC_B}{d\tau} \right|_{\tau=\tau_{opt}} = 0$$

where

$$\tau = \frac{V}{v_0}$$



Courtesy of Prof. David Rockstraw, New Mexico State University.

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Problem 6-14c (modified): Producing D



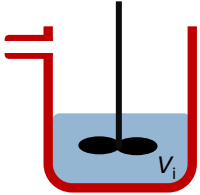
10 min

The product D is to be produced through the rxn of A with B in an isothermal semibatch reactor initially filled with one of the reactants while the other is continuously fed to the reactor. The following rxns take place:

$A + 2B \longrightarrow C + D$ $2D + 3A \longrightarrow C + E$ $B + 2C \longrightarrow D + F$

$r_{D1} = k_{D1} C_A C_B^2$ $r_{E2} = k_{E2} C_A C_D$ $r_{F3} = k_{F3} C_B C_C^2$

Feed
 v_0

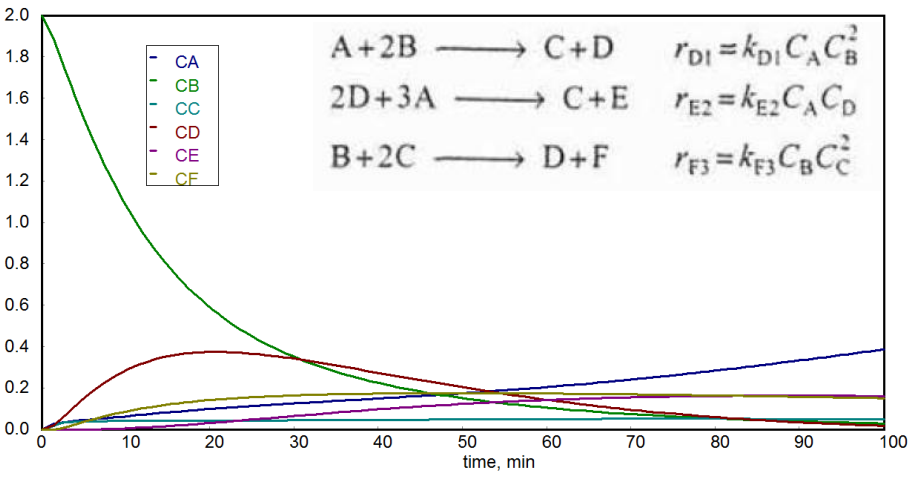


Additional information: constant density-liquid phase rxn

$k_{D1} = 0.25 \text{ L}^2/\text{mol}^2.\text{min}$, $k_{E2} = 0.1 \text{ L}/\text{mol}.\text{min}$, $k_{F3} = 5 \text{ L}^2/\text{mol}^2.\text{min}$,
 $v_0 = 1 \text{ L}/\text{min}$, $V_i = 40 \text{ L}$, $C_{A, \text{pure}} = 1.5 \text{ mol}/\text{L}$, $C_{B, \text{pure}} = 2 \text{ mol}/\text{L}$.

- Determine which of the reactants should be initially charged and which should be continuously fed. Justify your choice.
- Plot the species concentrations, X , overall S , & overall Y as a function of time.
- What are the max C_D and N_D and when are they reached?
- Inspect the C_i profiles and discuss how $C_{D|\text{max}}$ can be further increased.

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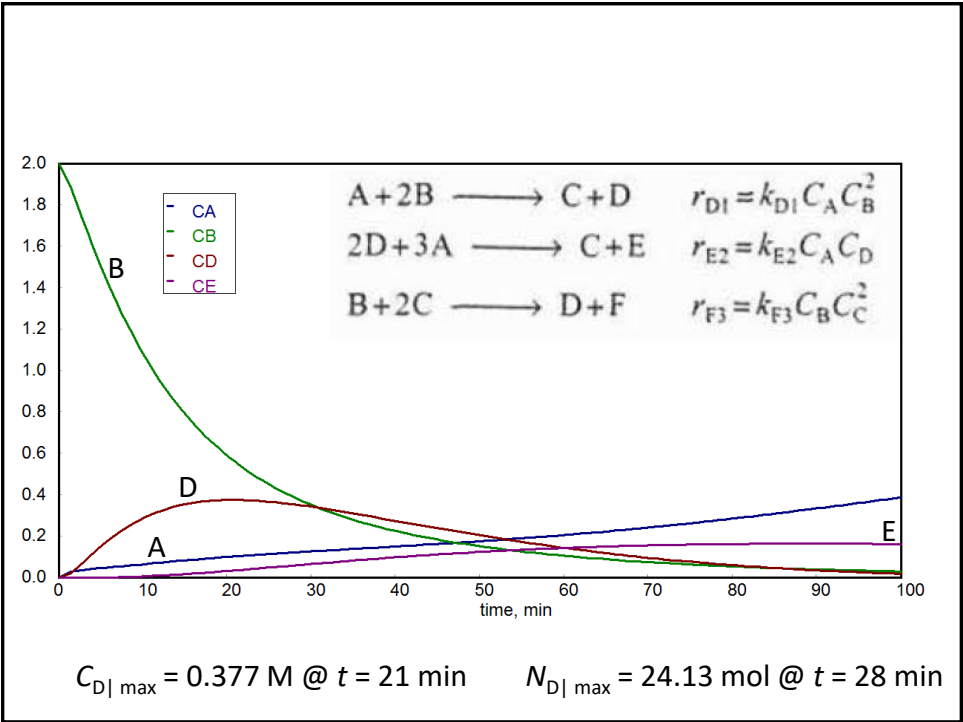
$A + 2B \longrightarrow C + D$ $2D + 3A \longrightarrow C + E$ $B + 2C \longrightarrow D + F$

$r_{D1} = k_{D1} C_A C_B^2$ $r_{E2} = k_{E2} C_A C_D$ $r_{F3} = k_{F3} C_B C_C^2$

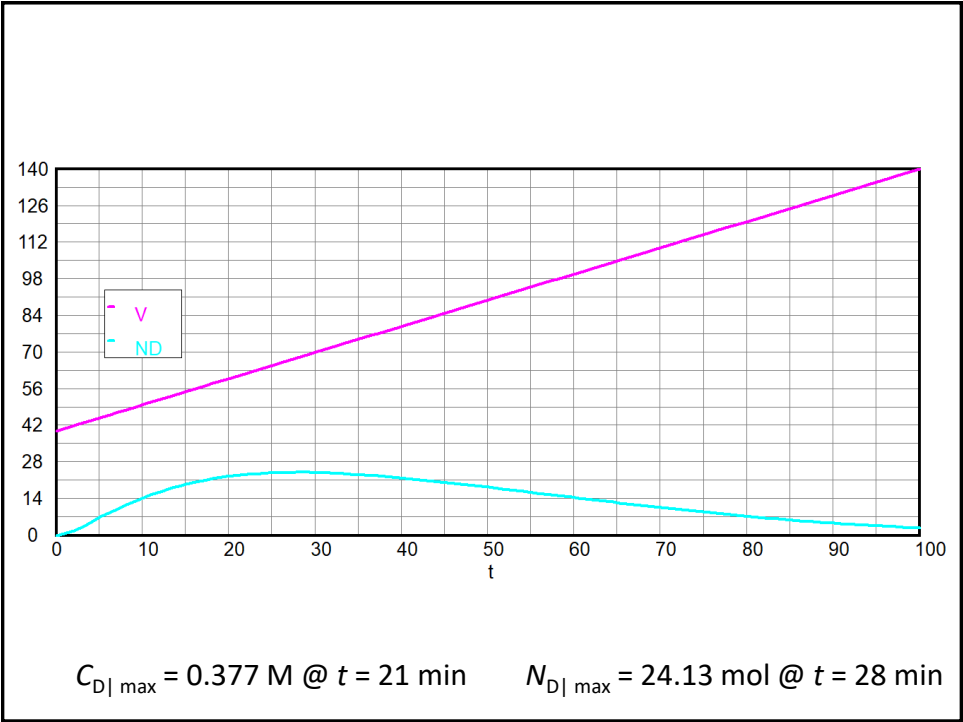
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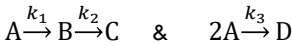


1. Van de Vusse Reactive System (35 min)
2. Trambouze Reactions (15 min)

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Example: Van de Vusse Reaction in an CSTR

Van de Vusse liquid phase reaction is carried out in an isothermal CSTR according to the following stoichiometric equations:



where B is the desired product, and C and D are the undesired byproducts. The feed to the CSTR contains the reactant A only. The reaction rates are given by the following rate laws:

$$-r_{A1} = k_1 C_A, \quad -r_{B2} = k_2 C_B, \quad -r_{A3} = k_3 C_A^2$$

Additional information: $k_1 = 0.8333 \text{ min}^{-1}$, $k_2 = 1.667 \text{ min}^{-1}$, $k_3 = 0.1667 \text{ L min}^{-1} \text{ mol}^{-1}$, $V = 7 \text{ L}$, $C_{A0} = 10 \text{ mol/L}$, $\nu_0 = 4 \text{ L/min}$.

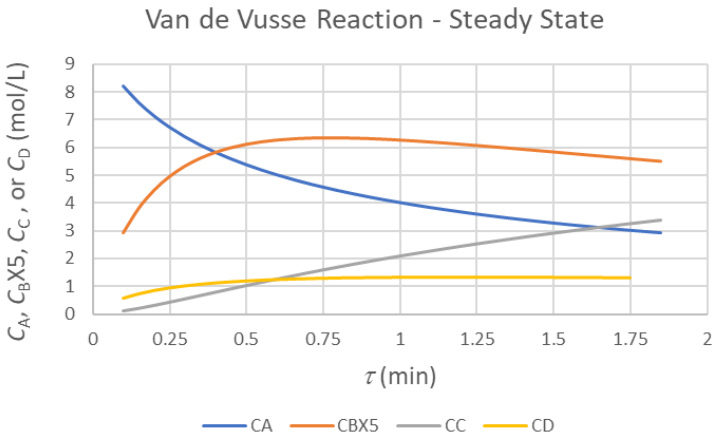
1. Calculate the species concentrations (C_i) and the selectivity and yield at steady state for the given conditions.
2. Plot C_i vs τ . Find the optimum τ .
3. For the specified V , calculate the optimum ν_0 . 4. For the specified ν_0 , calculate the optimum V .
5. Is this an acceptable reactor scheme/condition to use for this reaction? Explain your answer and show how the selectivity & yield can be further increased.
6. Plot the concentration profiles during the startup, where the reactor is initially filled with a solvent only and its volume is maintained constant.

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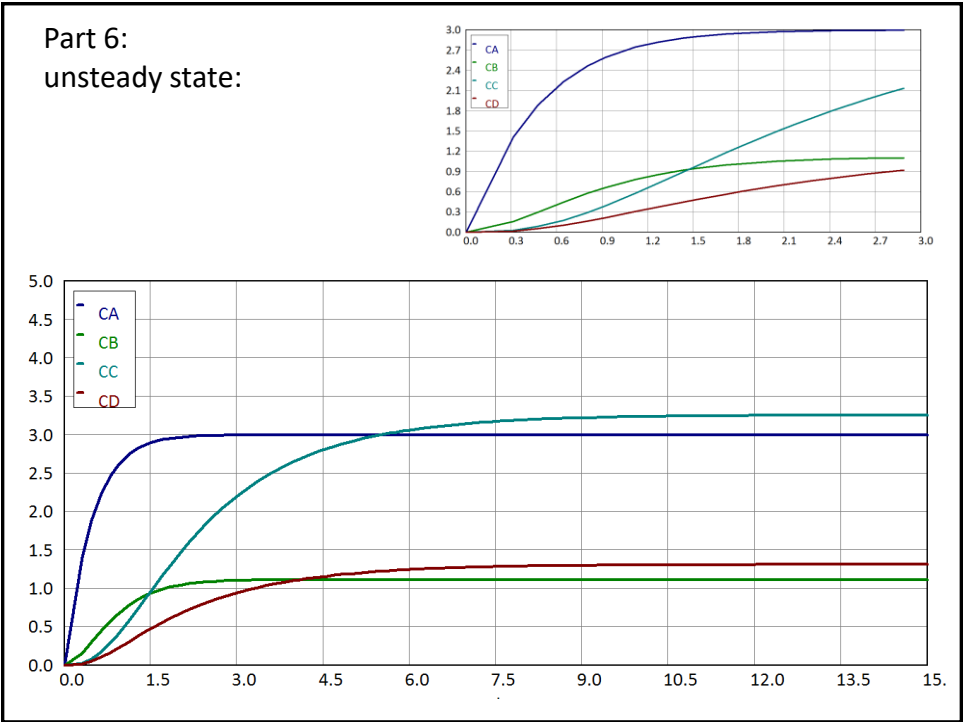
Part 1: @ steady state & $\tau = 1.75 \text{ min}$:

τ	C_A	C_B	C_C	C_D	Selectivity $S_{B/(C+D)}$		Yield $Y_{B/A}$	
					Instan.	Overall	Instan.	Overall
1.75	3.00	1.12	3.26	1.31	0.2444	0.2444	0.1596	0.1596

Part 2: $C_{B| \text{max}} = 1.266 \text{ mol/L}$ @ $\tau_{| \text{optimum}} = 0.775 \text{ min}$



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Part 6: unsteady state:

Calculated values of DEQ variables

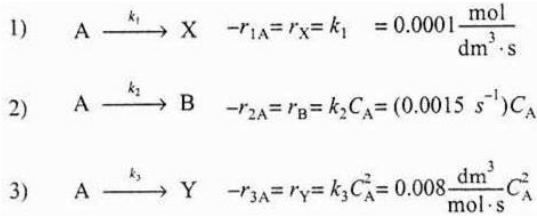
	Variable	Initial value	Minimal value	Maximal value	Final value
1	CA	0	0	2.999917	2.999917
2	CA0	10.	10.	10.	10.
3	CB	0	0	1.116779	1.116779
4	CC	0	0	3.256801	3.256801
5	CD	0	0	1.312304	1.312304
6	k1	0.8333	0.8333	0.8333	0.8333
7	k2	1.667	1.667	1.667	1.667
8	k3	0.1667	0.1667	0.1667	0.1667
9	rA	0	-4.000048	0	-4.000048
10	rB	0	0	1.11454	0.6381596
11	rC	0	0	1.861671	1.861671
12	rD	0	0	0.7501084	0.7501084
13	t	0	0	15.	15.
14	tau	1.75	1.75	1.75	1.75
15	V	7.	7.	7.	7.
16	v0	4.	4.	4.	4.

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Example 6-2: Maximizing the Selectivity for Trambouze Reactions



Reactant A reforms by three simultaneous rxns to three products, one that is desired, B, and two that are undesired, X and Y. These gas-phase rxns, along with the appropriate rate laws, are called the Trambouze rxns.

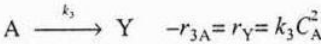
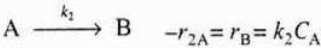
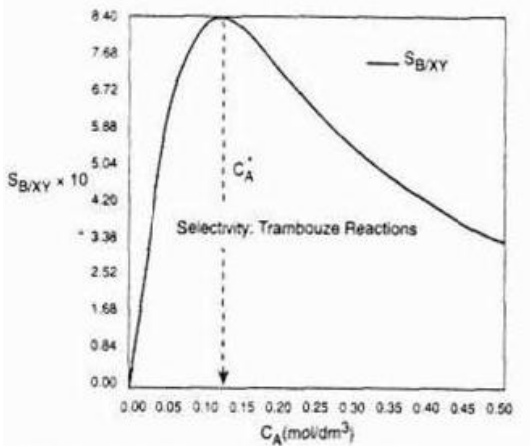


The specific rxn rates are given at the suggested operating T of 300 K (isothermal operation). The activation energies are $E_1 = 10,000$, $E_2 = 15,000$, and $E_3 = 20,000$ kcal/mol.

How and under what conditions (e.g., reactor types, temperature, concentrations) should the rxn be carried out to maximize the selectivity of B for C_{A0} of 0.4 M and a v_0 of 2.0 L/s?

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How do we increase the selectivity of B?
How to increase instantaneous selectivity?



$$S_{B/XY} = \frac{r_B}{r_X + r_Y} = \frac{k_2 C_A}{k_1 + k_3 C_A^2}$$

$$\frac{dS_{B/XY}}{dC_A} = 0$$

$$0 = \frac{k_2[k_1 + k_3 C_A^{*2}] - k_2 C_A^* [2k_3 C_A^*]}{[k_1 + k_3 C_A^{*2}]^2}$$

$$C_A^* = \sqrt{\frac{k_1}{k_3}} = 0.112 \text{ mol/L}$$

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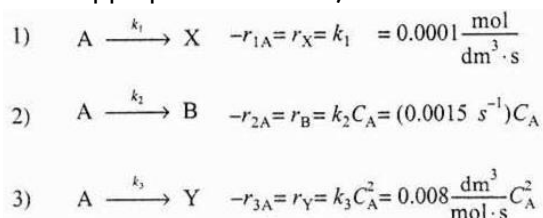
1. Trambouze Reactions (15 min)
2. Introduction to Energy Balance (35 min)

Prepared by: Dr Shaker Haji - CHENG 323

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Example 6-2: Maximizing the Selectivity for Trambouze Reactions

Reactant A reforms by three simultaneous rxns to three products, one that is desired, B, and two that are undesired, X and Y. These gas-phase rxns, along with the appropriate rate laws, are called the Trambouze rxns.



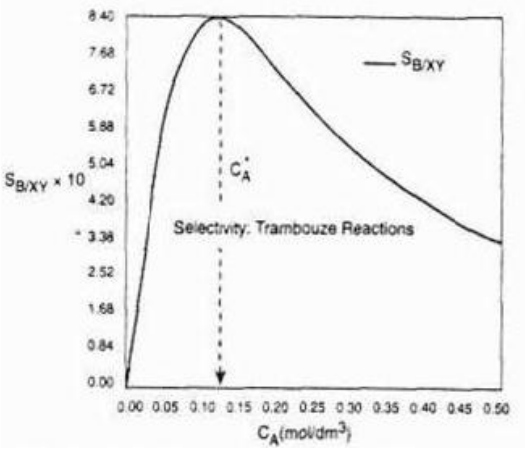
The specific rxn rates are given at the suggested operating T of 300 K (isothermal operation). The activation energies are $E_1 = 10,000$, $E_2 = 15,000$, and $E_3 = 20,000$ kcal/mol.

How and under what conditions (e.g., reactor types, temperature, concentrations) should the rxn be carried out to maximize the selectivity of B for C_{A0} of 0.4 M and a v_0 of 2.0 L/s?

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How do we increase the selectivity of B?

How to increase instantaneous selectivity?



$$A \xrightarrow{k_1} X \quad -r_{1A} = r_X = k_1$$
$$A \xrightarrow{k_2} B \quad -r_{2A} = r_B = k_2 C_A$$
$$A \xrightarrow{k_3} Y \quad -r_{3A} = r_Y = k_3 C_A^2$$

$$S_{B/XY} = \frac{r_B}{r_X + r_Y} = \frac{k_2 C_A}{k_1 + k_3 C_A^2}$$
$$\frac{dS_{B/XY}}{dC_A} = 0$$
$$0 = \frac{k_2[k_1 + k_3 C_A^{*2}] - k_2 C_A^* [2k_3 C_A^*]}{[k_1 + k_3 C_A^{*2}]^2}$$

$$C_A^* = \sqrt{\frac{k_1}{k_3}} = 0.112 \text{ mol/L}$$

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What is the optimum operating temperature? (considering that we already know what the optimum C_A is)

$$S_{B/XY} = \frac{k_2 C_A^*}{k_1 + k_3 C_A^{*2}} = \frac{k_2 \sqrt{\frac{k_1}{k_3}}}{k_1 + k_1} = \frac{k_2}{2\sqrt{k_1 k_3}}$$
$$S_{B/XY} = \frac{A_2}{2\sqrt{A_1 A_3}} \exp\left[\frac{\frac{E_1 + E_3}{2} - E_2}{RT}\right]$$

$E_1 = 10,000 \text{ kcal/mol}$ $E_2 = 15,000 \text{ kcal/mol}$ $E_3 = 20,000 \text{ kcal/mol}$

Case 1: If $\frac{E_1 + E_3}{2} < E_2$ { Run at as high a temperature as possible with existing equipment and watch out for other side reactions that might occur at higher temperatures.

Case 2: If $\frac{E_1 + E_3}{2} > E_2$ { Run at low temperatures but not so low that a significant conversion is not achieved.

Case 3: If $\frac{E_1 + E_3}{2} = E_2$ { Maximum $S_{B/XY} \neq f(T)$ Run at the T of your choice

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Let's consider operating at the suggested T .

How can I make the CSTR operate at the optimum C_A (0.112 mol/L)?

What is the optimum CSTR volume?

$$A \xrightarrow{k_1} X \quad -r_{1A} = r_X = k_1$$
$$A \xrightarrow{k_2} B \quad -r_{2A} = r_B = k_2 C_A$$
$$A \xrightarrow{k_3} Y \quad -r_{3A} = r_Y = k_3 C_A^2$$

$V = 1566 \text{ dm}^3$



Different operating T 's have different optimum C_A 's. Operating at higher T will reduce the value of the optimum C_A (i.e., X will be higher), but the required V will be smaller due to the higher rxn rates.

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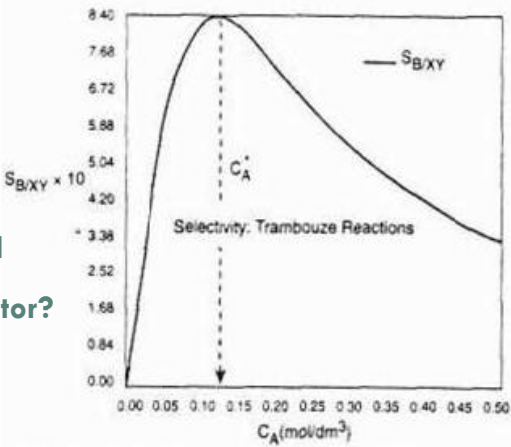
At the suggested T (300 K), optimum $C_A = 0.112 \text{ mol/L}$ at exit of CSTR.

This corresponds to

$$X = (F_{A0} - F_A) / F_{A0} = 72\%$$

What if 90% conversion is desired?

Which reactor type you would recommend for the 2nd reactor?



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At the suggested T (300 K), optimum $C_A = 0.112 \text{ mol/L}$ at exit of CSTR.

This corresponds to

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What if 90% conversion is desired?

Which reactor type you would recommend for the 2nd reactor?

Graph showing Selectivity: $S_{B/XY}$ versus C_A (mol/dm³). The curve peaks at $C_A^* = 0.112$ mol/dm³.

Process flow diagram showing two CSTRs in series. The first reactor has an inlet concentration $C_{A0} = 0.4 \text{ M}$ and an outlet concentration $C_A = 0.112 \text{ M}$. The second reactor has an inlet concentration $C_A = 0.112 \text{ M}$ and an outlet concentration $C_A = 0.04 \text{ M}$.

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Note 1

Note 2

Complete:

- Suggested Problems #8
- Chap 6 Examples
- tic-tac-toe game

Quiz #5

7-10 days from now (according to the schedule)

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