Asynchronous Learning of Chemical Reaction Engineering

Revitalization of Chemical Engineering Workshop III

June 12, 2003

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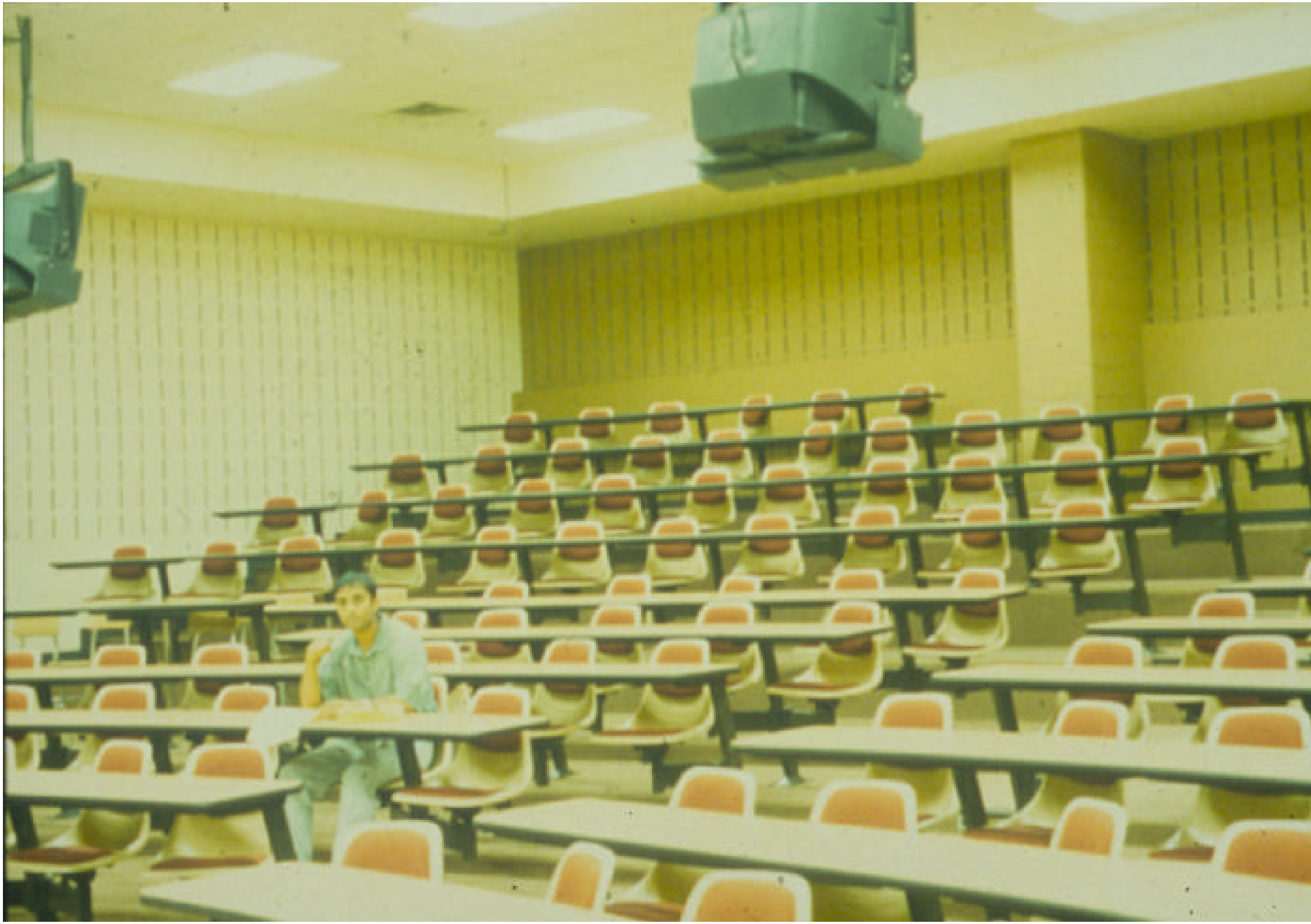
MichiganEngineering

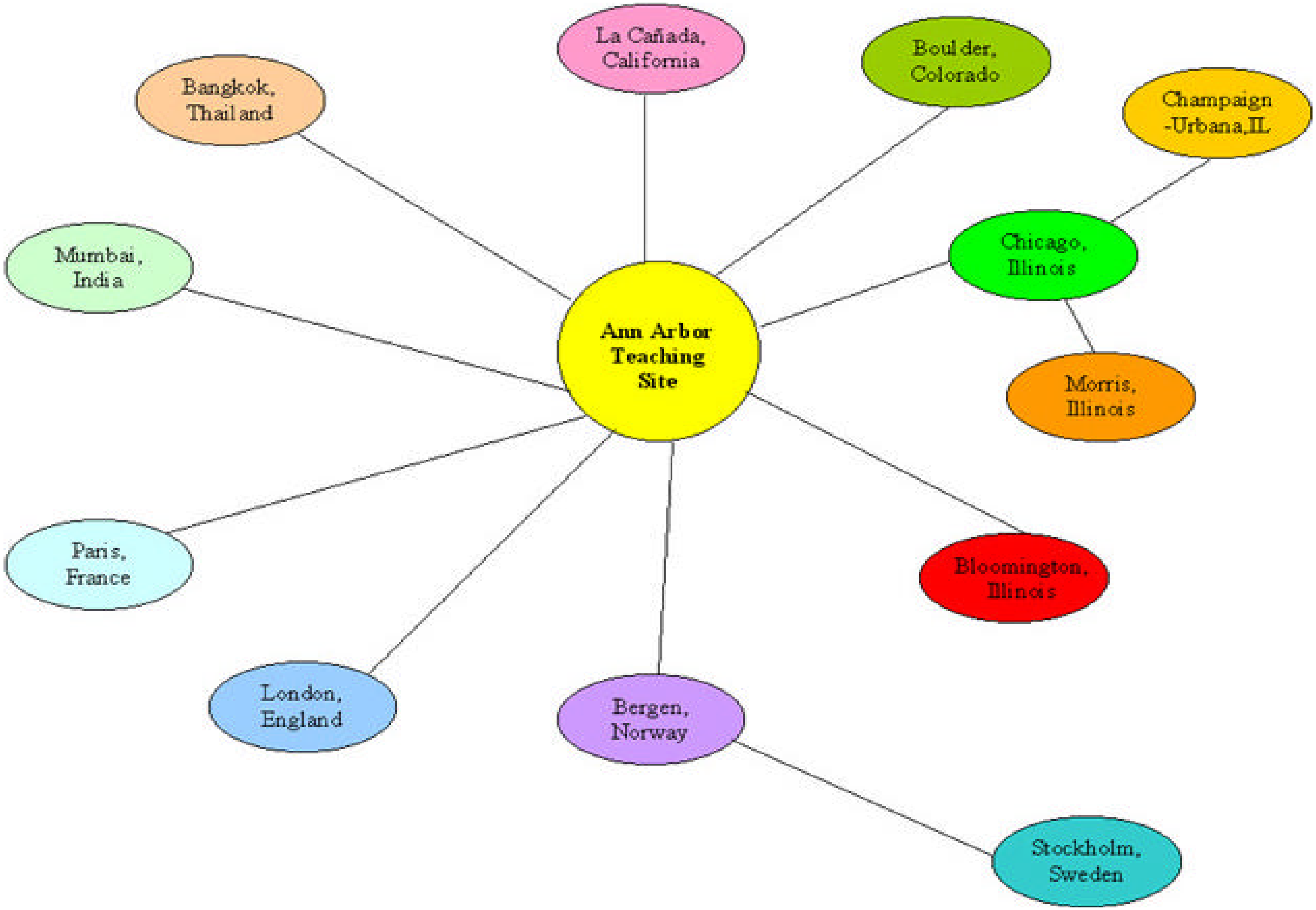
Introduction

Asynchronous Learning (AL) means that students learn at different times and locations. Asynchronous Learning is a part of Problem Based Learning because students are given a homework problem set to work on and they and they must then find and use the necessary learning resources to solve the problem.



Asynchronous Learning

Students can be located both with and outside the United States



Asynchronous Learning

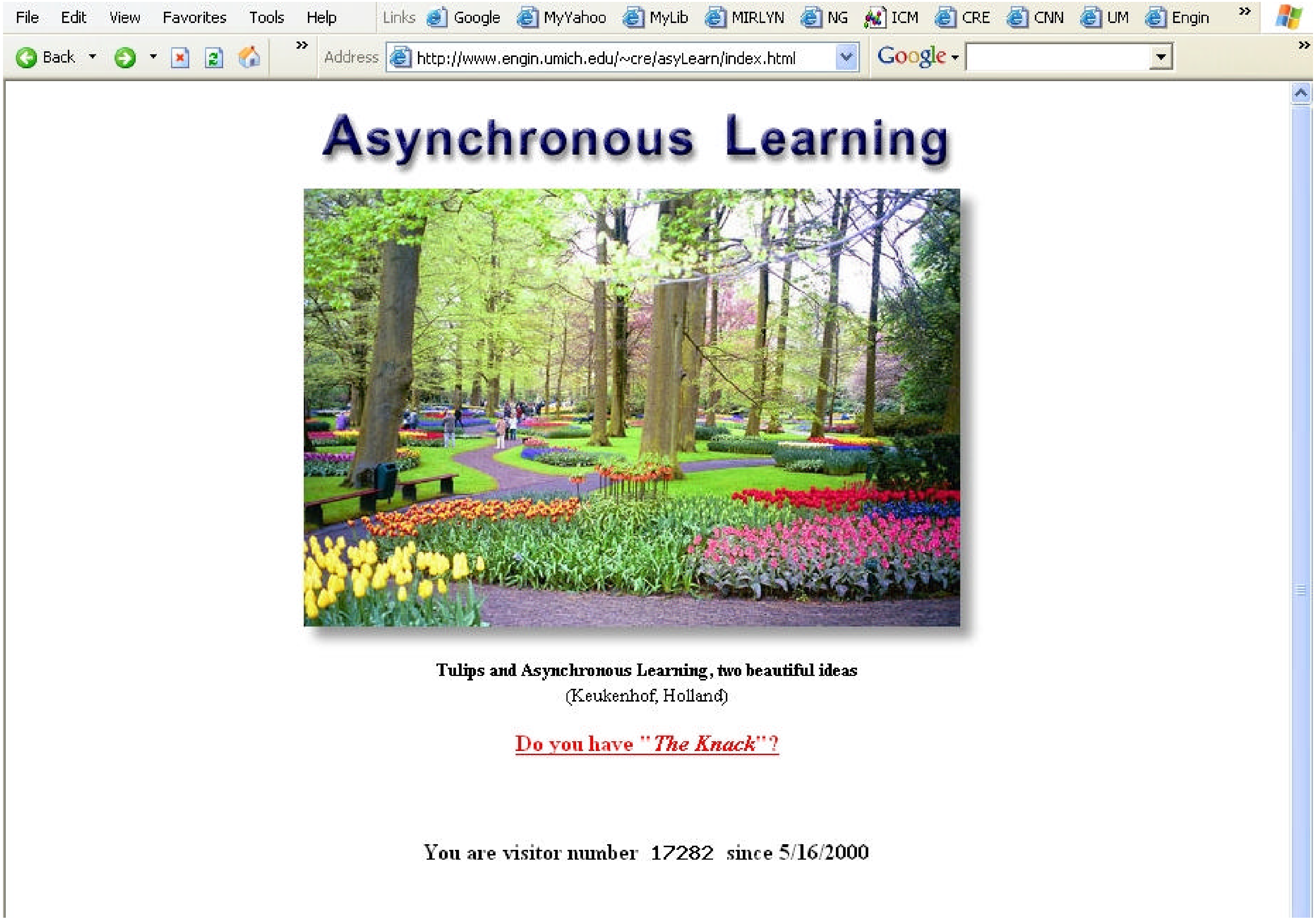
- With increased focus on technology, AL is rapidly becoming an alternative to traditional lecture-based classes (synchronous learning).

- AL also has the advantage of accommodating students who are on a co-op assignment or who can not make it on a regular basis to lecture.

- Some feel that a better description of AL is Location Independent Learning (LIL)

- ChE 344, Chemical Reaction Engineering (CRE), is the first class offered asynchronously in the chemical engineering department at the University of Michigan.

Asynchronous Learning Main Web Page

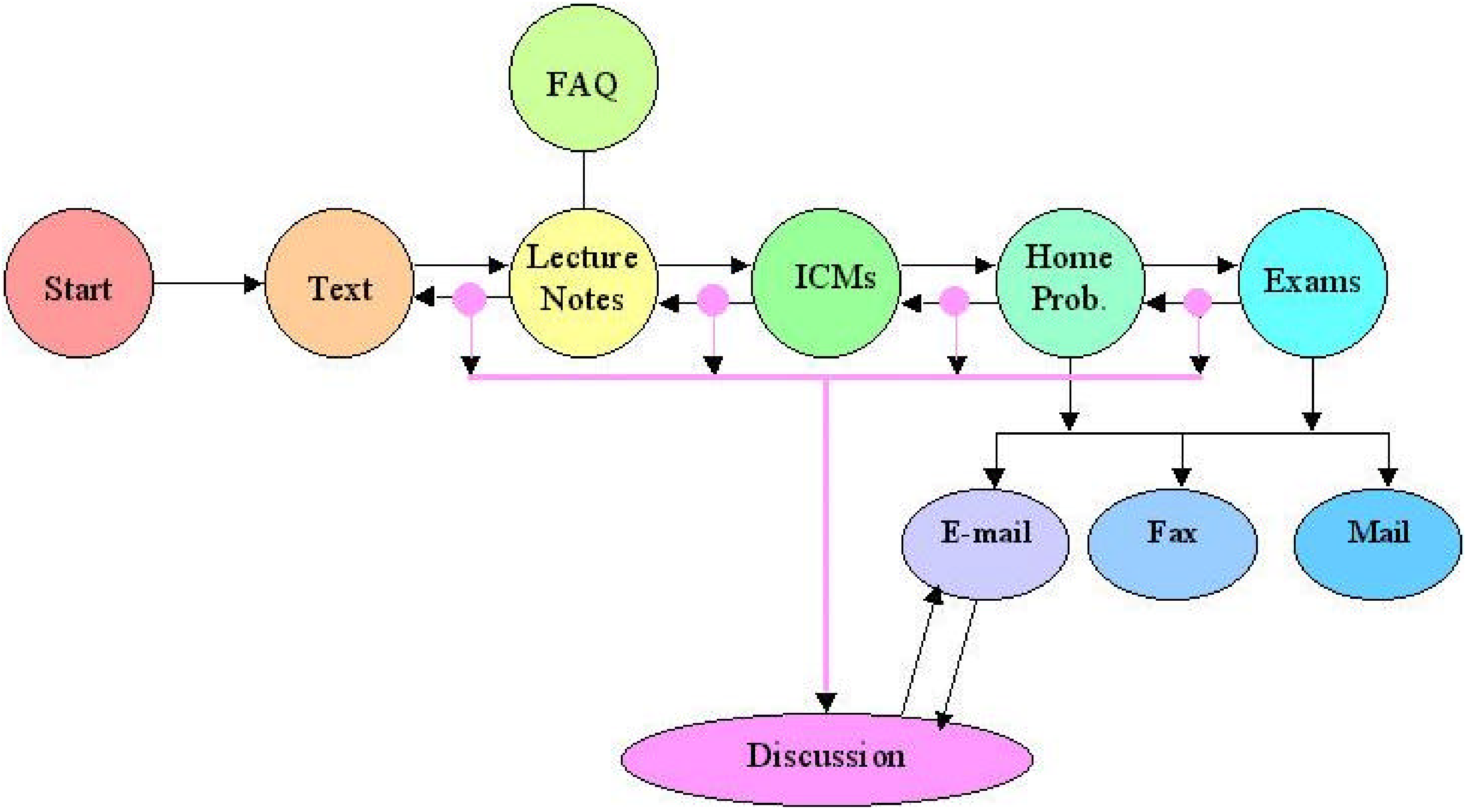


CDROM/WEB Resources

- Chapter outlines
- Web modules
- Summer notes with audio notes
- Equation derivations
- Self tests
- Video Clips
- Living example problems
- FAQ's
- Interactive computer modules

Asynchronous Learning

The student progression for the asynchronous CRE course at the University of Michigan is shown below:



CRE - Asynchronous Learning

Unit 11

Energy Balance and It's Application to the CSTR

Objectives	After completing Unit 11 of the text and associated CD-ROM material, the reader will be able to • Discuss each term in the energy balance • Describe the algorithm for CSTRs that are not operated isothermally • Size adiabatic and nonadiabatic CSTRs
Reading Assignment	Text: Chapter 8, pages 426-450 CD-ROM: Lecture Notes 13 and 14
	Time Estimate: 2 1/2 hours
Problem Assignment	CDROM ICMs: Review Section Only Heat Effects 1 Heat Effects 2 P8-6 Review all the audio clips and self tests in lectures 1-13. Pick three in each category that need to be improved. Explain why and how they need to be improved. Pick the two best in each category and explain why they are the best. Where would you suggest adding in audio clips? Finally, write a sentence stating the most confusing part in the text, on the lecture notes or add an FAQ. Email your answers to sfogler@umich.edu with a cc to byrnec@umich.edu .
	Time Estimate: 3 1/2 hours
Study Problems	P8-3 P8-4

Unit 11 Total Time Estimate: 6 hours

Critical and Creative Thinking

- **Thinking critically** is the process we use to reflect on, assess, and judge the assumptions underlying own and others’ ideas and actions.

- **Creative thinking** is the process we use to develop the ideas that are unique, useful, and worthy of further elaboration.

Felder/Soloman's Learning Style Inventory

- Active learners/Reflective learners
- Global learners/Sequential learners
- Visual learners/Verbal learners
- Sensing learners/Intuitive learners

Learning Styles Explained

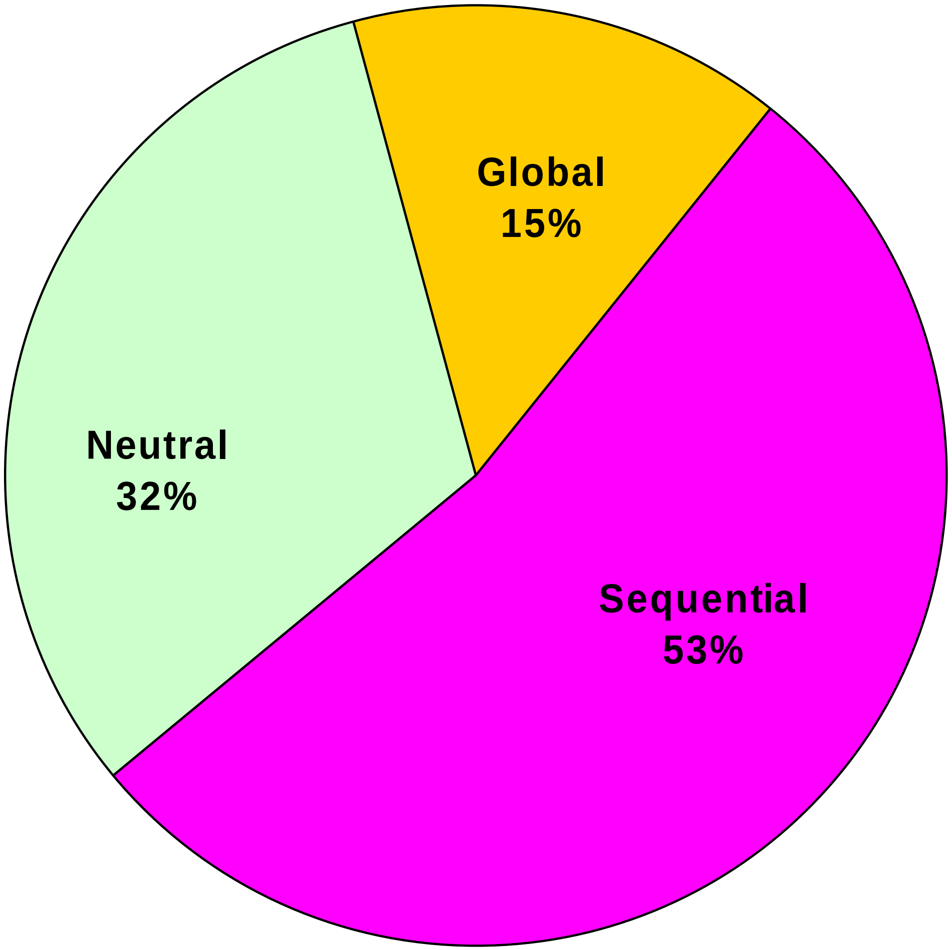
Global vs. Sequential learners

- Global learners tend to learn in large jumps, absorbing material almost randomly without seeing connections, and then suddenly "getting it".
- Sequential learners tend to gain understanding in linear steps, with each step following logically from the previous one.

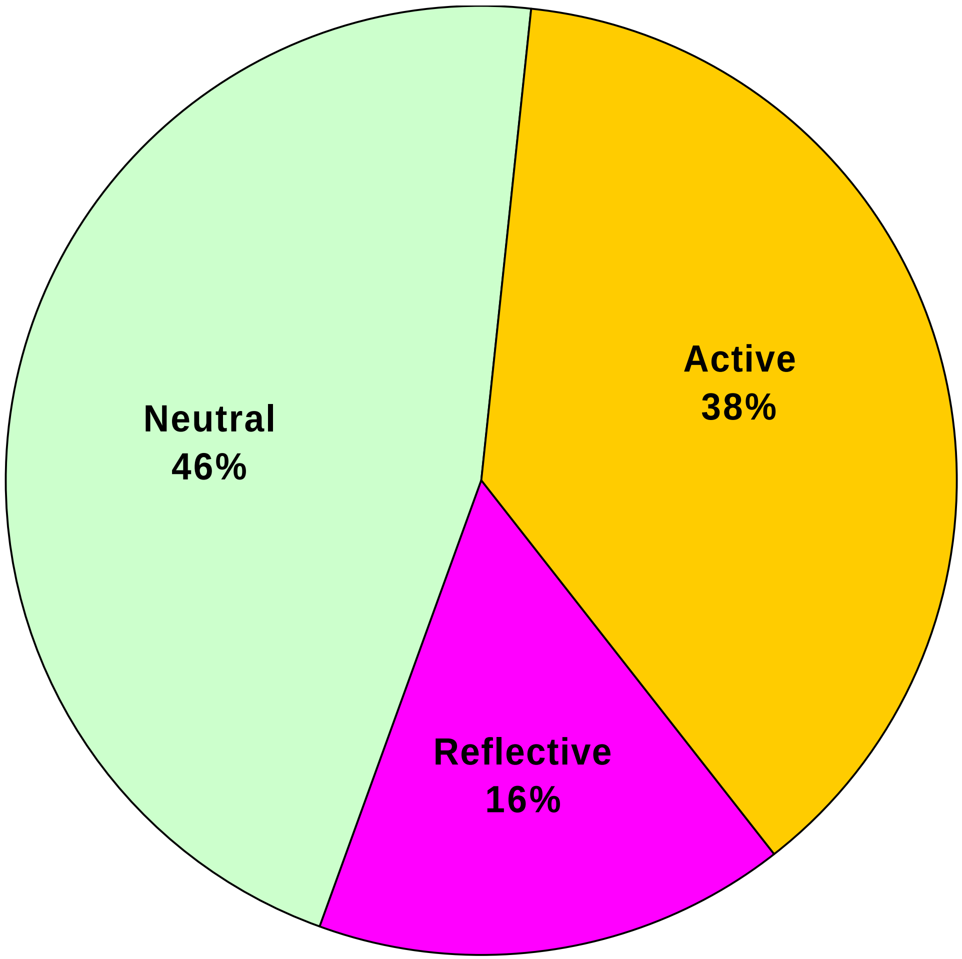
Active vs. Reflective learners

- Active learners like to learn by doing or trying things out in order to understand them.
- Reflective learners like to learn by reflecting, trying to understand things before experimenting with them.

Global vs. Sequential Learners



Active vs. Reflective

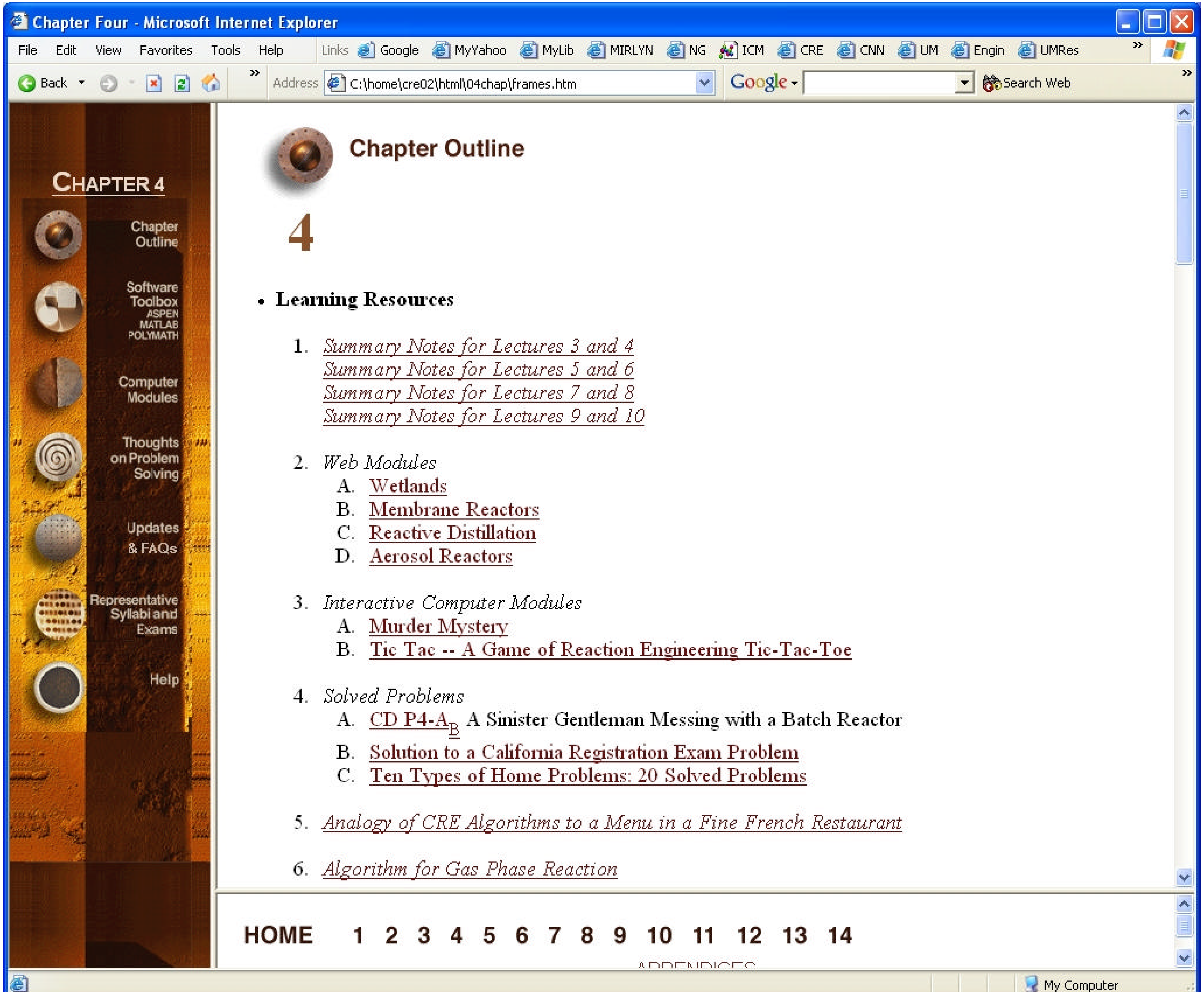


How the CD ROM and Web Can Help Your Learning Style

- Active
  - Use all the hot buttons to interact with the material
  - Use self tests as a good source of practice problems
  - Use living example problems to change settings/parameters and see the results
  - Review for exams using the ICM's
- Reflective
  - Self tests allow you to consider the answer before seeing it
  - Use web modules to think about topics independently

How the CD ROM and Web Can Help Your Learning Style

- Global
  - Use the summary lecture notes to get an overview of each chapter on the CD and see the big picture
  - Review real world examples and pictures on the CD
  - Look at concepts outlined in the Interactive Computer Modules (ICMs)
- Sequential
  - Use the *derive* hot button to go through the derivations in lecture notes on the web
  - Follow all derivations in the ICMs step by step
  - Do all self-tests, audios, and examples as you progress through the CD ROM lecture notes step by step.


Chapter Four - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Links Google MyYahoo MyLib MIRLYN NG ICM CRE CNN UM Engin UMRes
Back
Address C:\home\cre02\html\04chap\frames.htm
Google Search Web
CHAPTER 4
Chapter Outline
Software Toolbox ASPEN MATLAB POLYMATH
Computer Modules
Thoughts on Problem Solving
Updates & FAQs
Representative Syllabi and Exams
Help
Chapter Outline
4
• Learning Resources
1. Summary Notes for Lectures 3 and 4
Summary Notes for Lectures 5 and 6
Summary Notes for Lectures 7 and 8
Summary Notes for Lectures 9 and 10
2. Web Modules
A. Wetlands
B. Membrane Reactors
C. Reactive Distillation
D. Aerosol Reactors
3. Interactive Computer Modules
A. Murder Mystery
B. Tic Tac -- A Game of Reaction Engineering Tic-Tac-Toe
4. Solved Problems
A. CD P4-A_B A Sinister Gentleman Messing with a Batch Reactor
B. Solution to a California Registration Exam Problem
C. Ten Types of Home Problems: 20 Solved Problems
5. Analogy of CRE Algorithms to a Menu in a Fine French Restaurant
6. Algorithm for Gas Phase Reaction
HOME 1 2 3 4 5 6 7 8 9 10 11 12 13 14
My Computer

Updates & FAQs

Frequently Asked Questions (FAQs)

Chapter 4

1. **In solving problems for this class, is there ever a case where you need more steps than the mole balance, rate law, stoichiometry, and combining? (When do you deviate from this algorithm?)**

   We will always use this basic algorithm and then just add to these steps to it, e.g. the energy balance. We will not deviate from these first four steps.

2. **What specifically causes a CSTR in series to have a higher conversion than a CSTR in parallel?**

   The CSTR is always operating a the lowest concentration, the exit concentration. When say two CSTRs are in series, the first operates at a higher concentration, therefore the rate is greater, therefore the conversion is greater. The second reactor in series builds on the conversion in the first reactor. The conversion in the parallel scheme is the same as the conversion to the first reactor to the series scheme. See Figure p.50 and Example 4-2.

3. **When are reactors in parallel used since it seems as though reactors in series would always achieve higher conversion?**

   The PBRs in parallel are ued when there would otherwise be a large pressure drop in one long reactor or identically several PBRs connected in series.

4. **Is it possible to have a pressure drop for a liquid phase reaction, as is possible for a gas phase reaction?**

Lecture Outlines

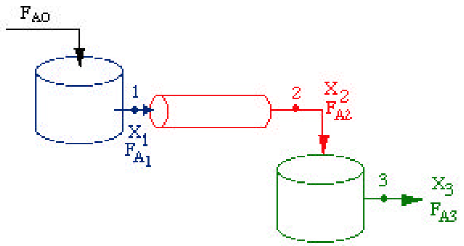
Reactors in Series

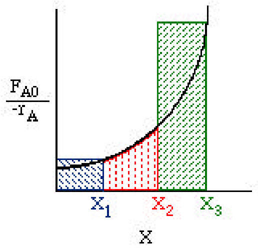
Given $-r_A$ as a function of conversion, one can also design any sequence of reactors:

$$X_i = \frac{\text{moles of A reacted up to point i}}{\text{moles of A fed to first reactor}}$$

Only valid if there are no side streams

Consider a PFR between two CSTRs





$$V_1 = \frac{F_{A0}X_1}{-r_{A_1}}$$

$$V_2 = \int_{X_1}^{X_2} \frac{F_{A0}}{-r_{A_2}} dX$$

$$V_3 = \frac{F_{A0}(X_3 - X_2)}{-r_{A_3}}$$

Example **Reactors in Series**

Index - Microsoft Internet Explorer

Address http://www.engin.umich.edu/~cre/course/lectures/one/mast

You can tell the overall reaction order by the units of k

C_A	$-r_A$	Reaction Order	Rate Law	k
(mol/dm^3)	(mol/dm^3*s)	zero	$-r_A = k$	(mol/dm^3*s)
		1st	$-r_A = kC_A$	s^{-1}
		2nd	$-r_A = kC_A^2$	($dm^3/mol*s$)

Example **Activation Energy**

Self Test **Crickets**

Rate Laws (p. 73)

Example: If the rate law for the non-elementary reaction

$$A + B \rightarrow C + D$$

is found to be

$$-r_A = kC_A^2 C_B$$

then the reaction is said to be 2nd order in A, 1st order in B, and 3rd order overall.

Elementary Reactions (p. 75)

A reaction follows an *elementary rate law* **if and only if the (iff)** stoichiometric coefficients are the same as the individual reaction order of each species. For the reaction in the previous example ($A + B \rightarrow C + D$), the rate law would be:

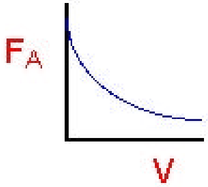
$$-r_A = kC_A C_B$$

if $2NO + O_2 \rightarrow 2NO_2$ then $-r_{NO} = k_{NO} C^2_{NO} C_{O2}$ if elementary!

Lecture Notes

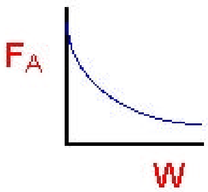
Include colored notes with audio clips, examples, and self-tests.

PFR $\frac{dF_A}{dV} = r_A$ $V = \int_{F_{A0}}^{F_A} \frac{dF_A}{r_A}$



Derive

PBR $\frac{dF_A}{dW} = r'_A$ $W = \int_{F_{A0}}^{F_A} \frac{dF_A}{r'_A}$



Derive

Self Test Multiple Choice Questions

Self Test Batch Reactor Times

Self Test What's wrong with this solution? Chapter 1

Self Assessment of Chapter Objectives Chapter 1

Thoughts on Problem Solving: Sample Registration Exam Problem - Microsoft Internet Explorer

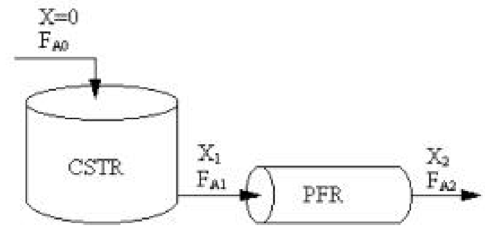
Address: http://www.engin.umich.edu/~cre/probsolv/closed/Alg/CRE-E

HOME > CLOSED > ALGORITHM > CRE EXAMPLES

SREP - Part II :CSTR & PFR

4. Identify and Name:

A. Relative Theories and Equations



Algebraic Form of CSTR equation:

$$V_{CSTR} = \frac{F_{A0}X_1}{-r_{A1}}$$

derive CSTR volume

For reactors in series, such as a PFR after a CSTR, the integral form of a PFR equation becomes:

$$V_{PFR} = F_{A0}\int_{X_1}^{X_2} \frac{dX_2}{-r_{A2}}$$

derive PFR volume

B. Systems

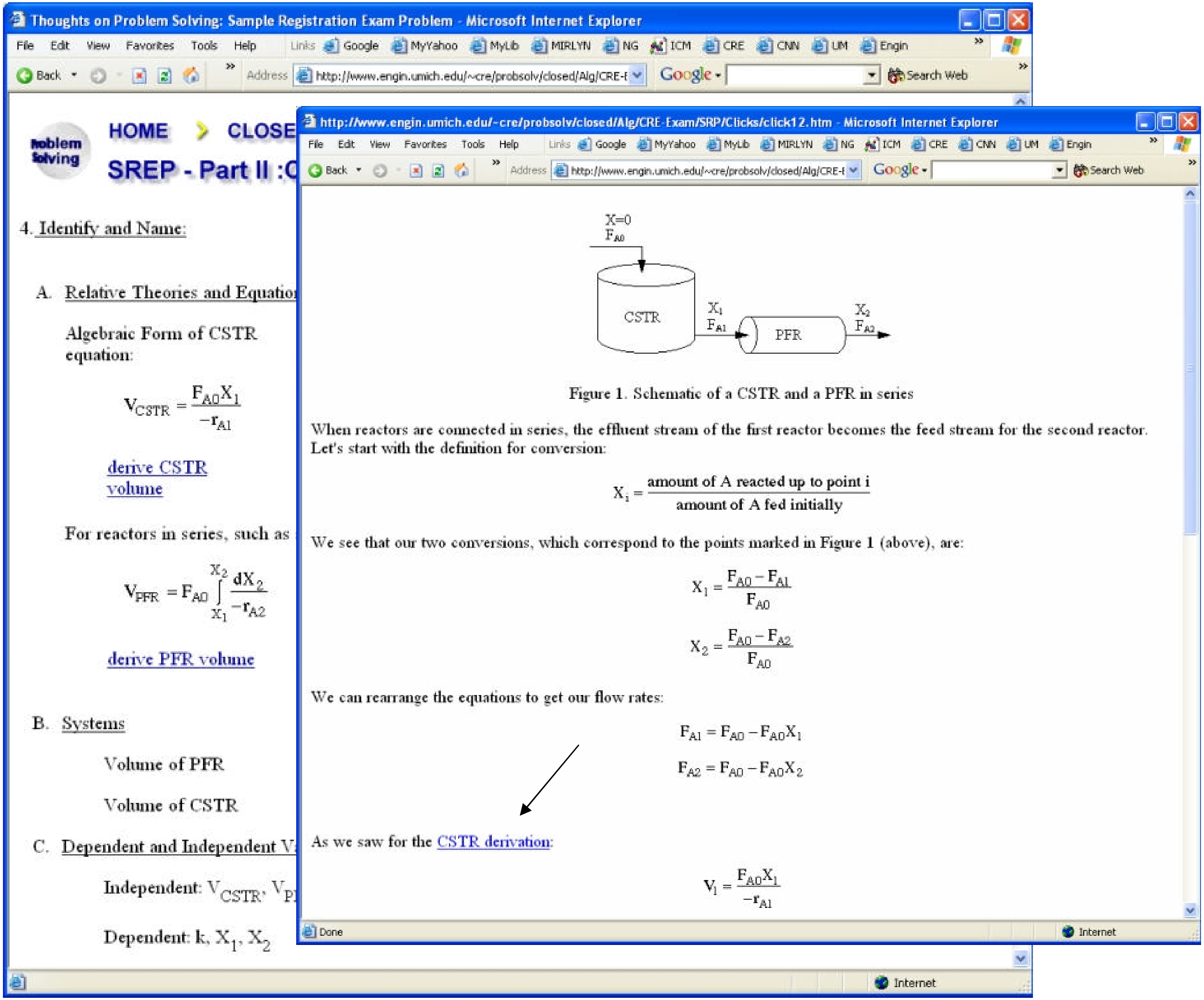
Volume of PFR

Volume of CSTR

C. Dependent and Independent Variables

Independent: V_{CSTR}, V_{PFR}, F_{A0}, F_{B0}, T

Dependent: k, X_1, X_2



Thoughts on Problem Solving: Sample Registration Exam Problem - Microsoft Internet Explorer

HOME > CLOSE

SREP - Part II :C

4. Identify and Name:

A. Relative Theories and Equation

Algebraic Form of CSTR equation:

$$V_{CSTR} = \frac{F_{A0}X_1}{-r_{A1}}$$

derive CSTR volume

For reactors in series, such as

$$V_{PFR} = F_{A0}\int_{X_1}^{X_2}\frac{dX_2}{-r_{A2}}$$

derive PFR volume

B. Systems

Volume of PFR

Volume of CSTR

C. Dependent and Independent V

Independent: V_{CSTR}, V_{P}

Dependent: k, X_1, X_2

http://www.engin.umich.edu/~cre/probsolv/closed/Alg/CRE-Exam/SRP/Clicks/click12.htm - Microsoft Internet Explorer

Figure 1. Schematic of a CSTR and a PFR in series

When reactors are connected in series, the effluent stream of the first reactor becomes the feed stream for the second reactor. Let's start with the definition for conversion:

$$X_i = \frac{\text{amount of A reacted up to point i}}{\text{amount of A fed initially}}$$

We see that our two conversions, which correspond to the points marked in Figure 1 (above), are:

$$X_1 = \frac{F_{A0} - F_{A1}}{F_{A0}}$$

$$X_2 = \frac{F_{A0} - F_{A2}}{F_{A0}}$$

We can rearrange the equations to get our flow rates:

$$F_{A1} = F_{A0} - F_{A0}X_1$$

$$F_{A2} = F_{A0} - F_{A0}X_2$$

As we saw for the CSTR derivation:

$$V_1 = \frac{F_{A0}X_1}{-r_{A1}}$$

Thoughts on Problem Solving: Sample Registration Exam Problem - Microsoft Internet Explorer

HOME > CLOSE

SREP - Part II :C

http://www.engin.umich.edu/~cre/probsolv/closed/Alg/CRE-Exam/SRP/Clicks/click11.htm - Microsoft Internet ...

The general mole balance for a CSTR is:

[rate of flow of A into the system (moles/time)] + [rate of generation of A by chemical reaction within thesystem (moles/time)] − [rate of flow of Aout of the system (moles/time)] = [rate of accumulation of A within the system(moles/time)]

$$F_{A0} + r_{A1}V_1 - F_{A1} = \frac{dN_A}{dt}$$

We assume there are no spatial variations in the rate of reaction. At steady state:

$$\frac{dN_A}{dt} = 0$$

After some rearranging:

$$V_1 = \frac{F_{A0} - F_{A1}}{-r_{A1}}$$

Working in terms of conversion: $F_{A1} = F_{A0}(1\text{-}X_1)$

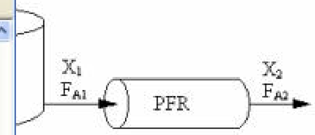
Substituting into the equation:

$$V_1 = \frac{F_{A0} - F_{A0}(1 - X_1)}{-r_{A1}}$$

$$V_1 = \frac{F_{A0} - F_{A0} + F_{A0}X_1}{-r_{A1}}$$

$$V_1 = \frac{F_{A0}X_1}{-r_{A1}}$$

http://www.engin.umich.edu/~cre/probsolv/closed/Alg/CRE-Exam/SRP/Clicks/click12.htm - Microsoft Internet Explorer



...atic of a CSTR and a PFR in series

...am of the first reactor becomes the feed stream for the second reactor.

...unt of A reacted up to point i / amount of A fed initially

...the points marked in Figure 1 (above), are:

$$X_1 = \frac{F_{A0} - F_{A1}}{F_{A0}}$$

$$X_2 = \frac{F_{A0} - F_{A2}}{F_{A0}}$$

$$F_{A1} = F_{A0} - F_{A0}X_1$$

$$F_{A2} = F_{A0} - F_{A0}X_2$$

$$V_1 = \frac{F_{A0}X_1}{-r_{A1}}$$

Self Tests

Allow for practice and understanding of lecture material

Elementary Reactions (p. 75)

A reaction follows an *elementary rate law* **if and only if the (iff)** stoichiometric coefficients are the same as the individual reaction order of each species. For the reaction in the previous example ($A + B \rightarrow C + D$), the rate law would be:

$$-r_A = kC_A C_B$$

if $2NO + O_2 \rightarrow 2NO_2$ then $-r_{NO} = k_{NO} C^2_{NO} C_{O2}$ if elementary!

Example More examples of Rate Laws

Self Test Rate Laws

Self Test - Rate Laws

What is the reaction rate law for the reaction

$$A + 1/2\ B \rightarrow C$$

if the reaction is elementary? What is r_B? What is r_C? Calculate the rates of A, B, and C in a CSTR where the concentrations are $C_A = 1.5$ mol/dm^3, $C_B = 9$ mol/dm^3 and $k_A = 2$ (dm^3/mol)$^{(1/2)}$(1/s).

Hint 1: What is $-r_A$?

Hint 2: What is r_B?

SELF TEST

What Four Things are Wrong with This Solution? - Chapter 3

Problem

The elementary gas phase reaction

$$3\,A + 2B \longrightarrow 3C + 5D$$

is carried out in a flow reactor operated isothermally at 427ÁC and 28.7 atmospheres. Pressure drop can be neglected. Express the rate law and the concentration of each species as a function of conversion and as a function of the total molar flow rates. The entering volumetric flow rate is 10 dm^3/s and the specific reaction rate is 200 dm^{12}/mol^{4}*s. The feed is equal molar in A and B.

Solution

$$3\,A + 2B \longrightarrow 3C + 5D$$

A is the limiting reactant

$$A + \frac{2}{3}B \longrightarrow C + \frac{5}{3}D$$

$$-r_A = kC_A C_B^{2/3}$$

$$C_A = \frac{C_{A0}(1-X)}{(1+\varepsilon X)}$$

$$\varepsilon = 3 + 5 - 2 - 3 = 3$$

$$C_A = C_{A0}\frac{(1-X)}{1+3X}$$

Main Menu

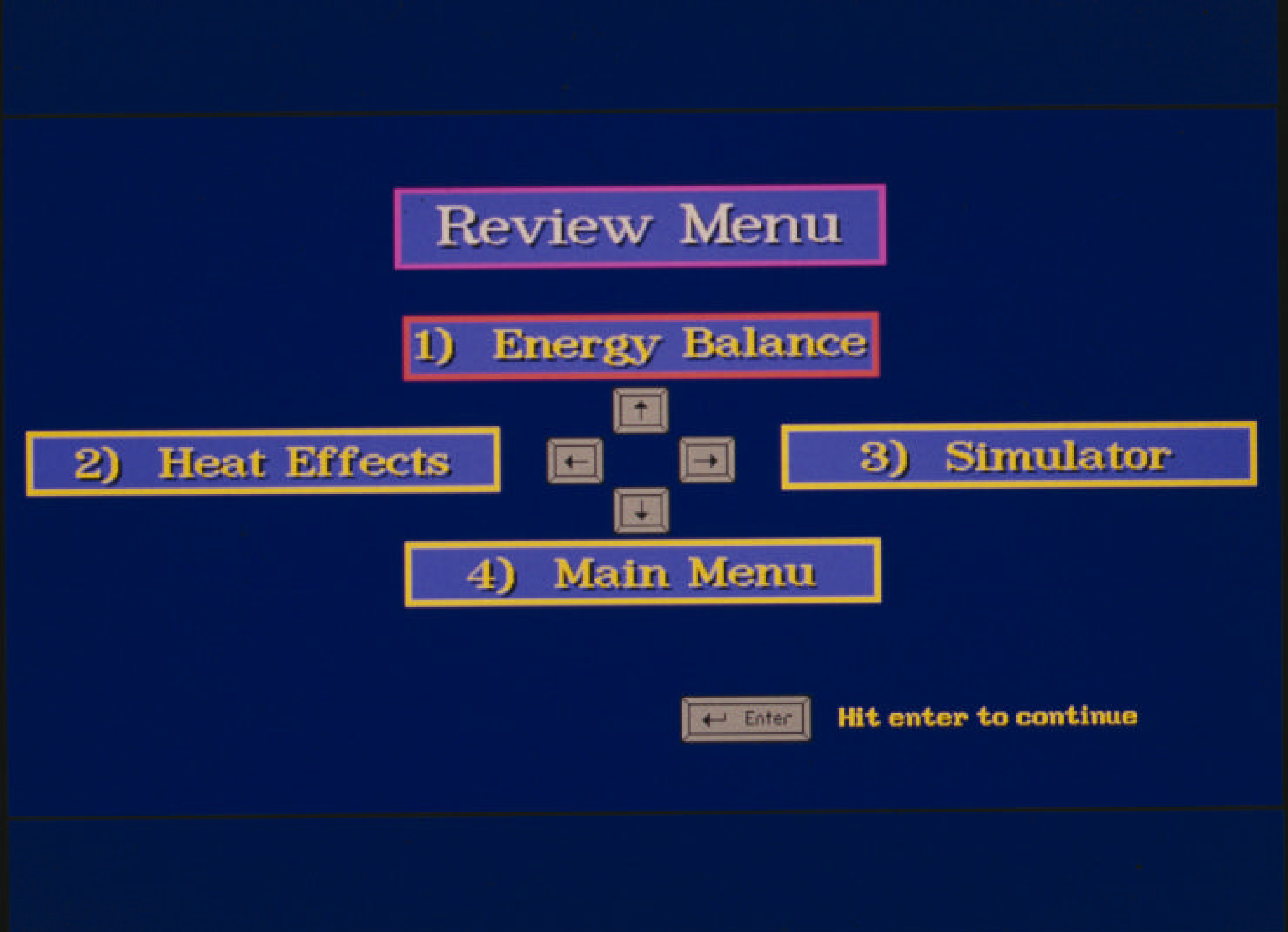
1. Introduction (Rules)

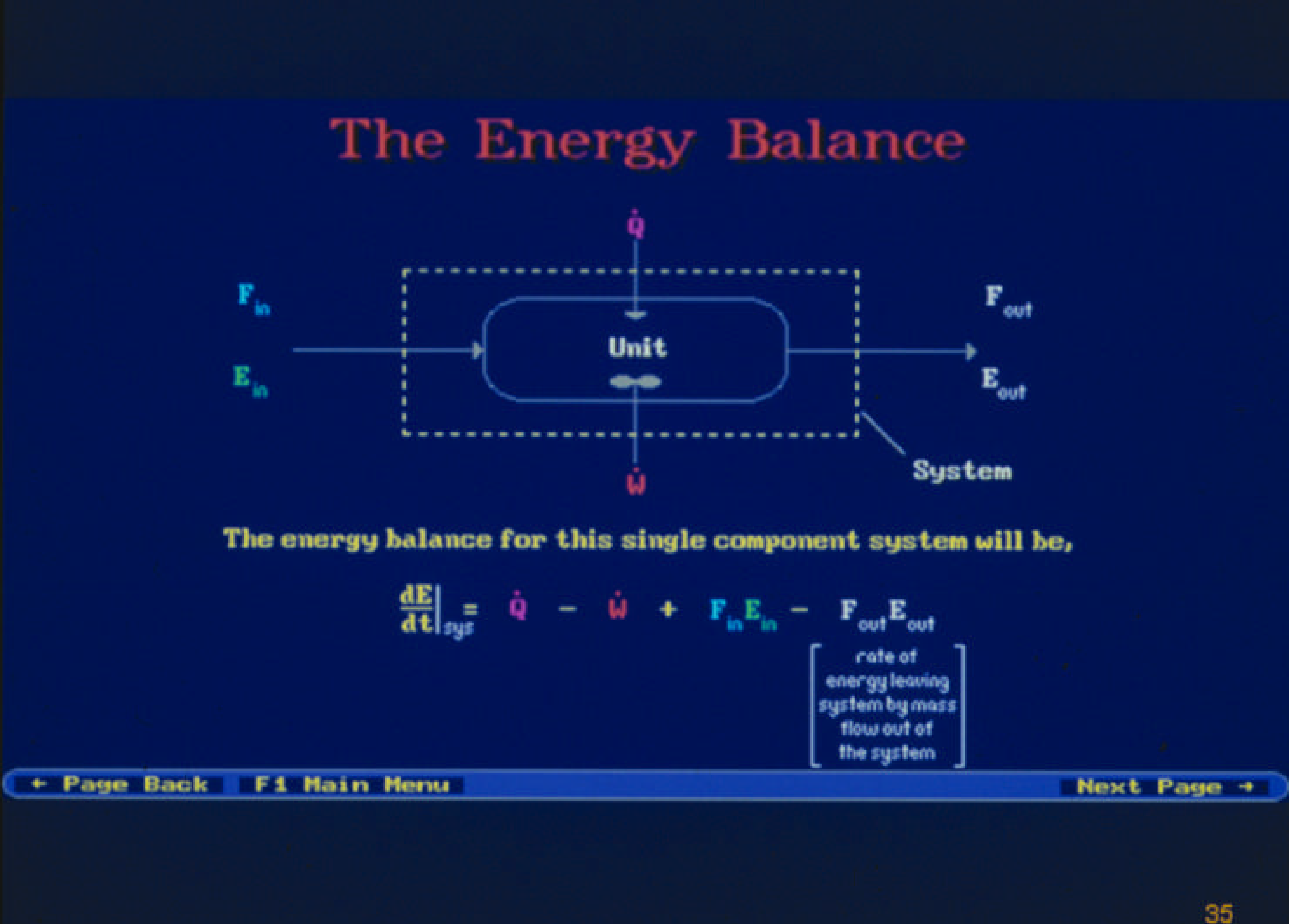
2. Review (Commercial Break)

3. Interaction (Introduce Contestants and Start the Game)

4. Exit Module

Please enter a number from 1-4 : _


Review Menu
1) Energy Balance
2) Heat Effects
3) Simulator
4) Main Menu
Enter
Hit enter to continue


The Energy Balance
Q
F_in
E_in
Unit
F_out
E_out
System
W
The energy balance for this single component system will be,
dE/dt|_sys = Q − W + F_in E_in − F_out E_out
rate of energy leaving system by mass flow out of the system
← Page Back
F1 Main Menu
Next Page →
35

$$\left.\frac{dE}{dt}\right|_{sys} = \dot{Q} - \dot{W} + \sum_{i=1}^{n} E_i F_i \Big|_{in} - \sum_{i=1}^{n} E_i F_i \Big|_{out}$$

We will now define the work term ($\dot{W}$).

$$\dot{W} = \underbrace{- \sum_{i=1}^{n} F_i P V_i \Big|_{in} + \sum_{i=1}^{n} F_i P V_i \Big|_{out}}_{\text{flow work}} + \dot{W}_s$$

→ to Continue

36

$$\dot{Q} - \dot{W}_s + F_{A0}\sum_{i=1}^{n}\Theta_i(H_{i0} - H_i) - F_{A0}X\sum_{i=1}^{n}\nu_i H_i = 0$$

Now we can integrate this expression.

$$\int_{H(T_R)}^{H} dH_i = \int_{T_R}^{T} C_{Pi}\,dT$$

To obtain,

Who are you ?

$$H_i - H_i(T_R) = \int_{T_R}^{T} C_{Pi}\,dT \qquad \Delta H_{Qi}$$

→ to Continue

37

$$\dot{Q} - \dot{W}_s + F_{A0}\sum_{i=1}^{n}\Theta_i(H_{i0} - H_i) - F_{A0}X\sum_{i=1}^{n}\nu_i H_i = 0$$

Now we can integrate this expression.

$$\int_{H(T_R)}^{H} dH_i = \int_{T_R}^{T} C_{Pi}\,dT$$

To obtain,

$$H_i - H_i(T_R) = \int_{T_R}^{T} C_{Pi}\,dT \qquad \Delta H_{Li}$$

I'm the phase change term.

→ to Continue

38

$$\dot{Q} - \dot{W}_s + F_{A0}\sum_{i=1}^{n}\Theta_i(H_{i0} - H_i) - F_{A0}X\sum_{i=1}^{n}\nu_i H_i = 0$$

Now we can integrate this expression.

$$\int_{H(T_R)}^{H} dH_i = \int_{T_R}^{T} C_{Pi}\, dT$$

To obtain,

We're neglecting you this time.

$$H_i - H_i(T_R) = \int_{T_R}^{T} C_{Pi}\, dT \qquad \Delta H_{iM}$$

→ to Continue

$$\dot{Q} - \dot{W}_s + F_{A0}\sum_{i=1}^{n}\Theta_i(H_{i0} - H_i) - F_{A0}X\sum_{i=1}^{n}\nu_i H_i = 0$$

Now we can integrate this expression.

$$\int_{H(T_R)}^{H} dH_i = \int_{T_R}^{T} C_{Pi}\, dT$$

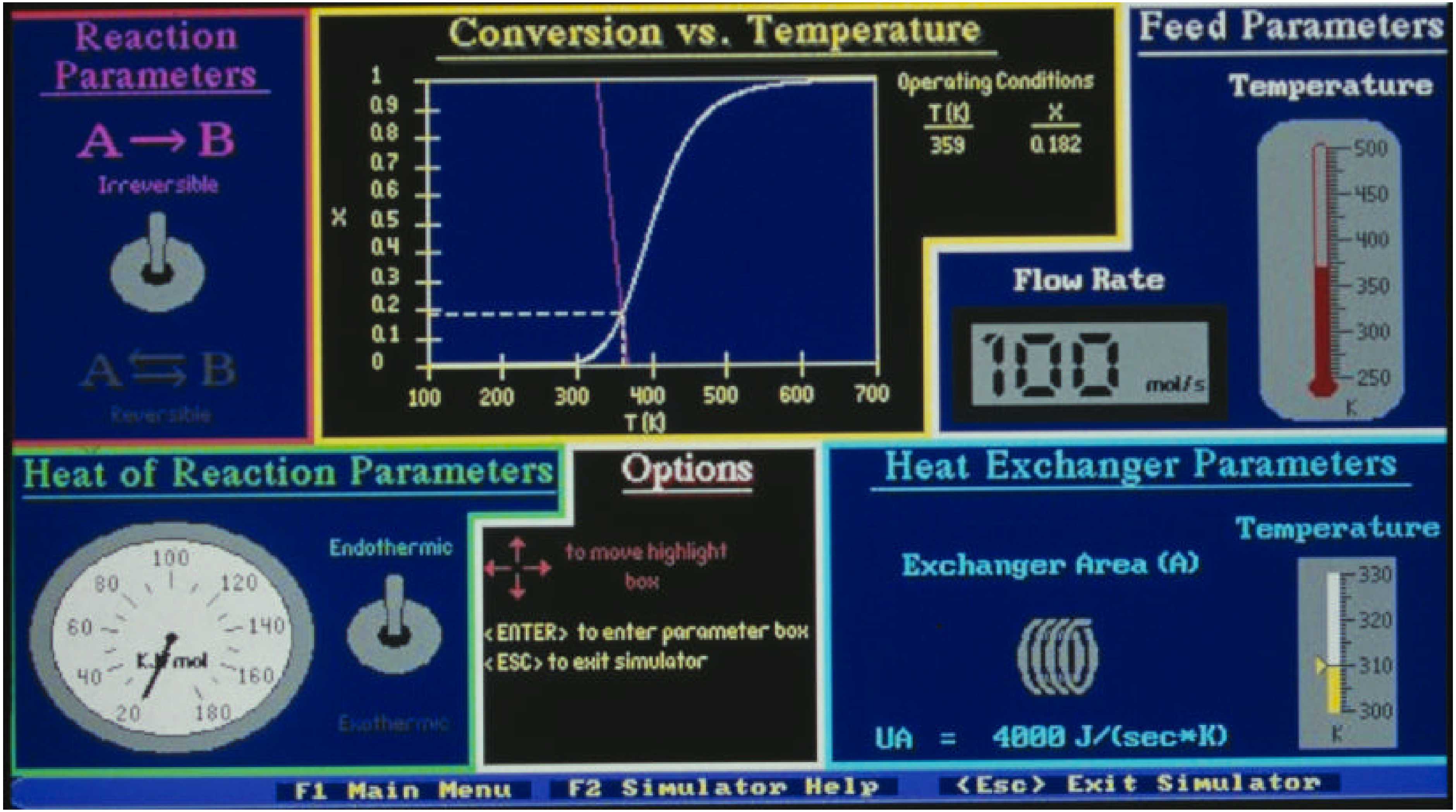
To obtain,

$$H_i - H_i(T_R) = \int_{T_R}^{T} C_{Pi}\, dT$$

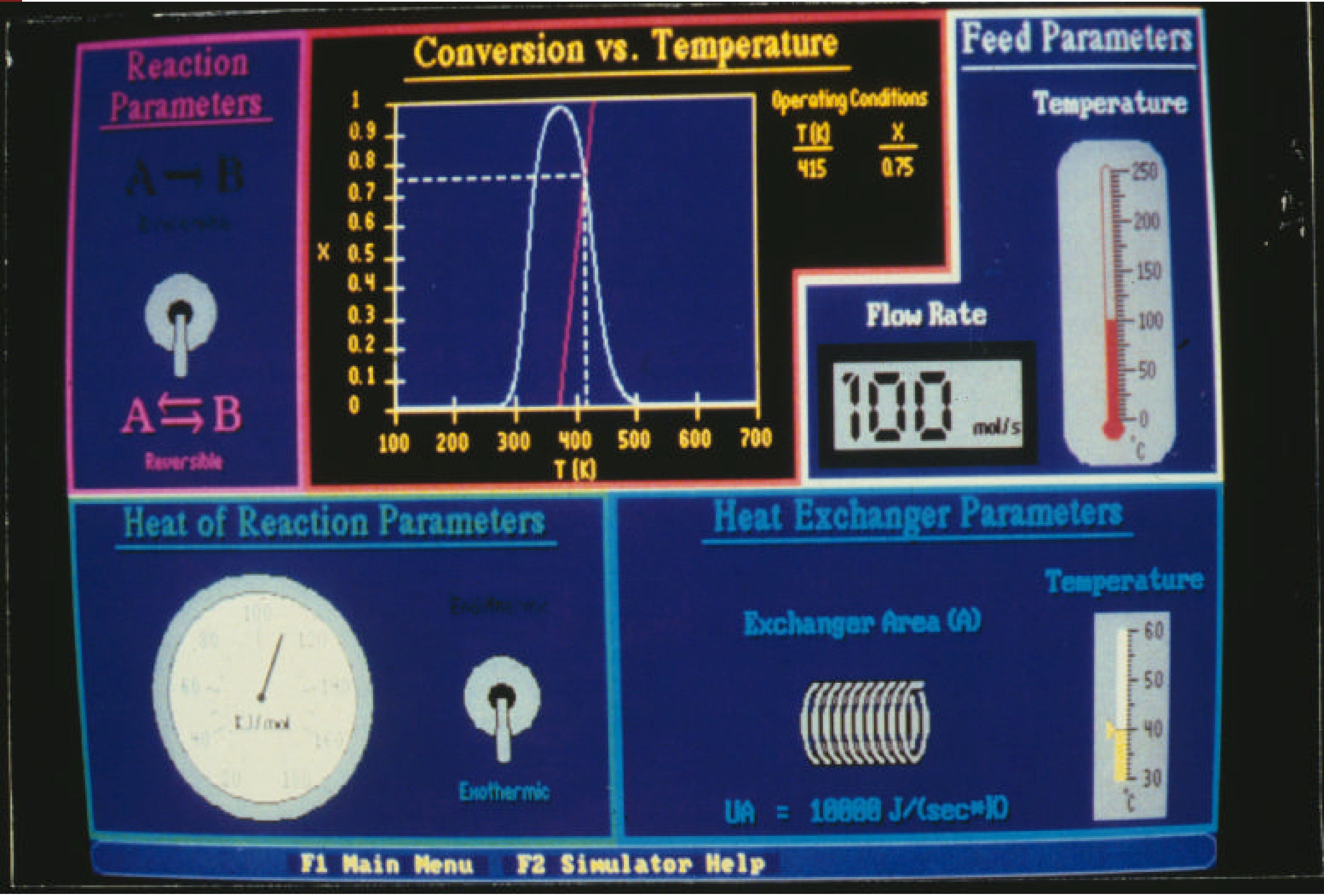
I feel so unwanted.

ΔH_{Rx}

→ to Continue



Reaction Parameters
A → B
Irreversible
A ⇆ B
Reversible
Conversion vs. Temperature
Operating Conditions
T (K) X
359 0.182
X
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
100 200 300 400 500 600 700
T (K)
Feed Parameters
Temperature
500
450
400
350
300
250
K
Flow Rate
100 mol/s
Heat of Reaction Parameters
100 80 120 60 140 40 160 20 180
KJ/mol
Endothermic
Exothermic
Options
to move highlight box
<ENTER> to enter parameter box
<ESC> to exit simulator
Heat Exchanger Parameters
Temperature
Exchanger Area (A)
330
320
310
300
K
UA = 4000 J/(sec*K)
F1 Main Menu
F2 Simulator Help
<Esc> Exit Simulator


Reaction Parameters
A → B
A ⇆ B
Reversible
Conversion vs. Temperature
Operating Conditions
T (K)
415
X
0.75
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
X
100
200
300
400
500
600
700
T (K)
Feed Parameters
Temperature
250
200
150
100
50
0
°C
Flow Rate
100
mol/s
Heat of Reaction Parameters
kJ/mol
Exothermic
Heat Exchanger Parameters
Exchanger Area (A)
Temperature
60
50
40
30
°C
UA = 10000 J/(sec*K)
F1 Main Menu
F2 Simulator Help

Kinetics Challenge I

Which of the following is a characteristic of an ideal CSTR ?

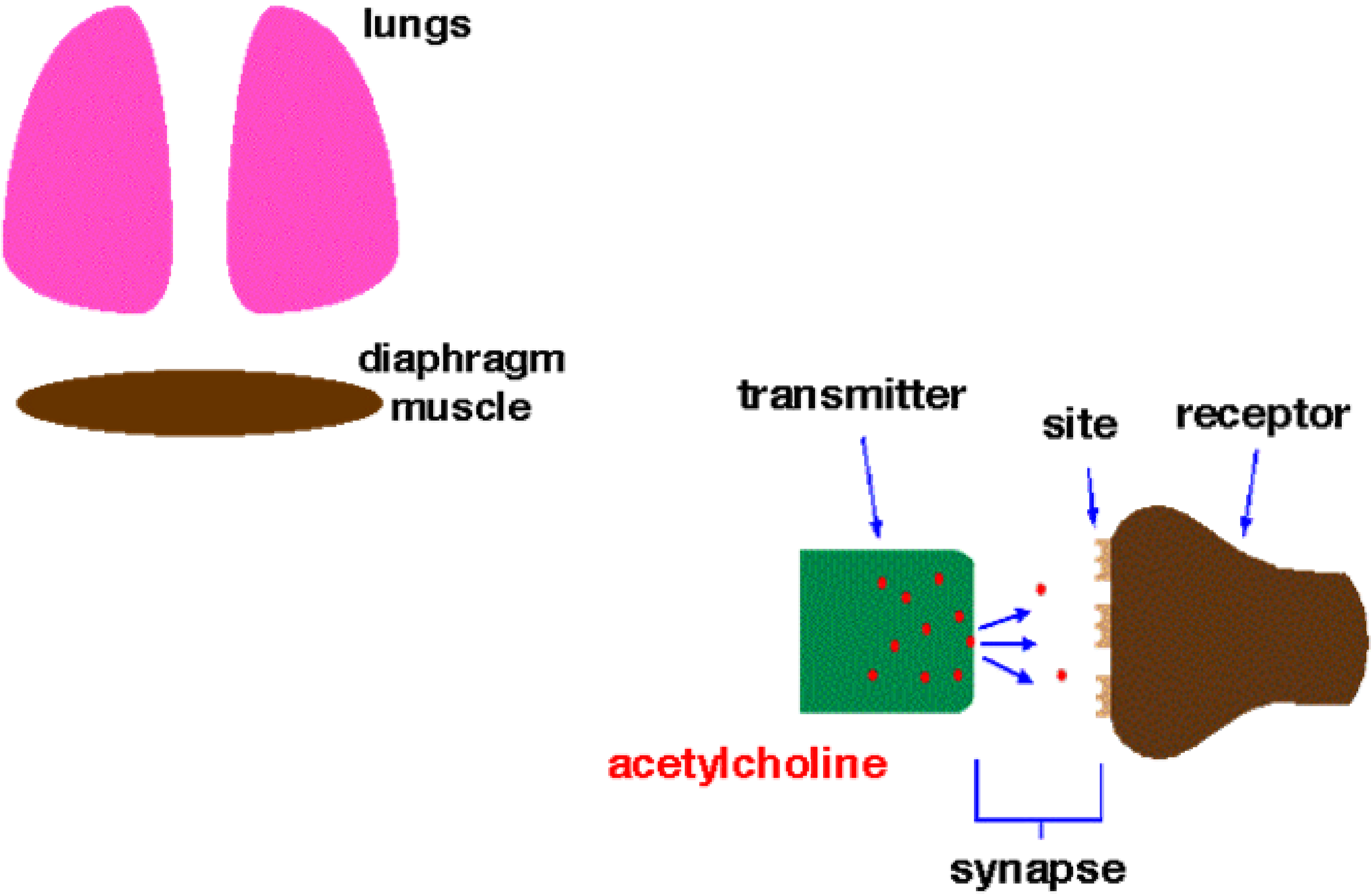
1. Intense mixing.
2. Minimal side reactions.
3. Hot spots.
4. A good personality.

Select an answer (1-4) or
<ESC> to forfeit (no gain or loss) :

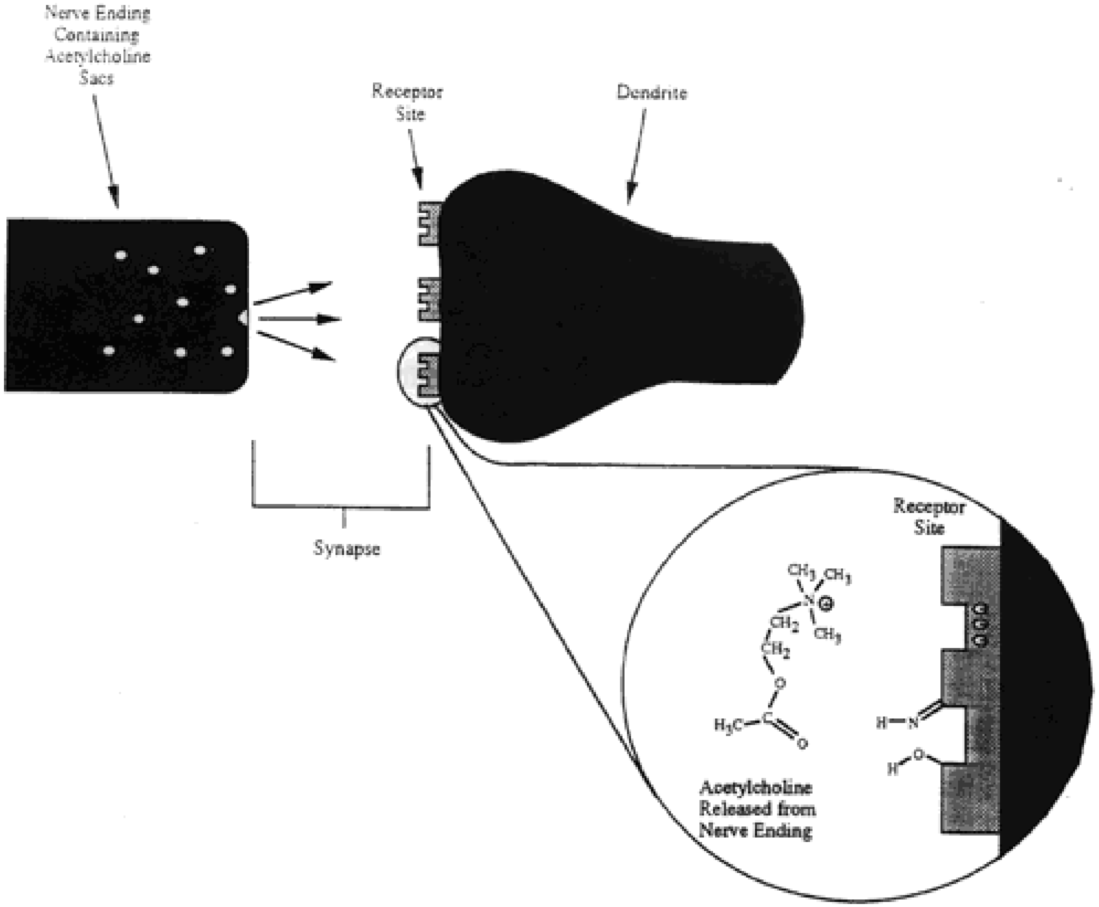
F3 Reference

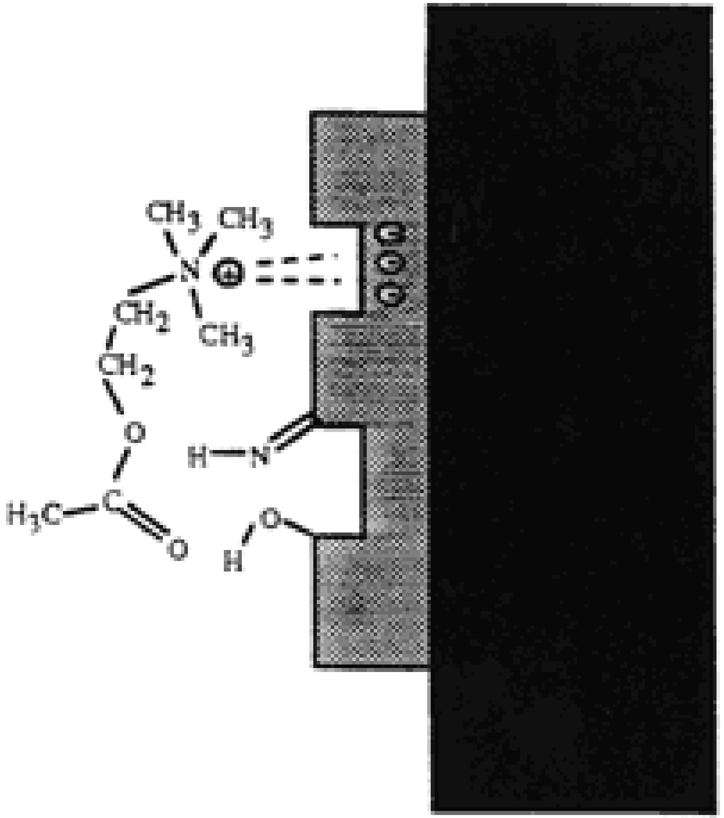
Venom kills within 30 minutes
Antivenom is only known treatment

Effects of Cobra Venom



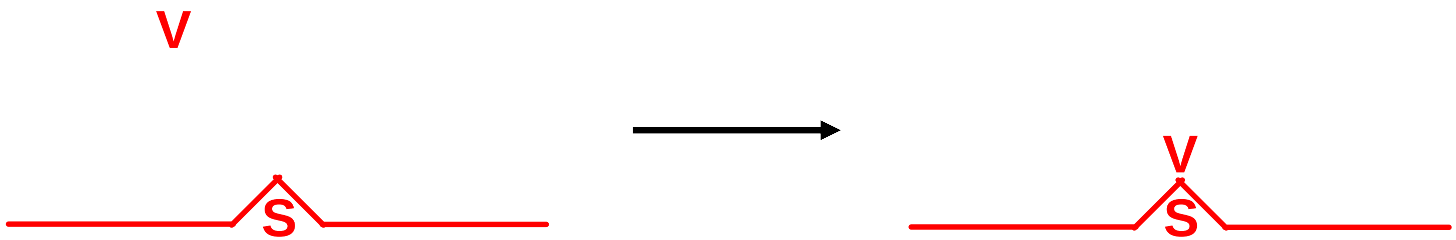
Effects of Cobra Venom





Cobra Venom Reactions

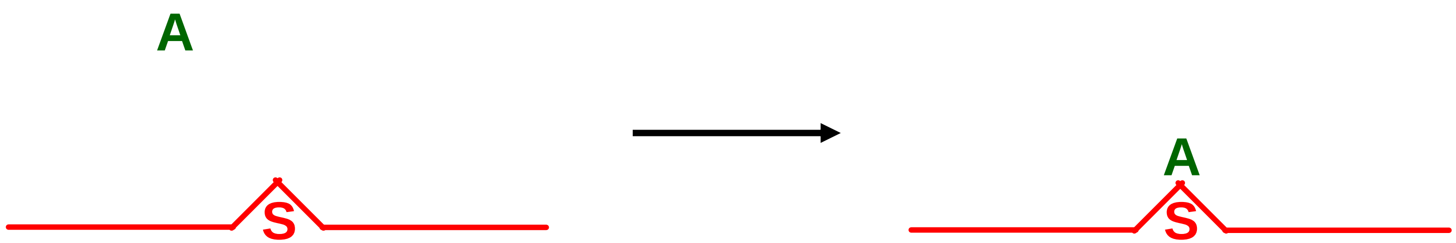
Adsorption of venom onto site:



V + **S** ⟶ **VS**

Rate constant = k_v

Adsorption of antivenom onto site:

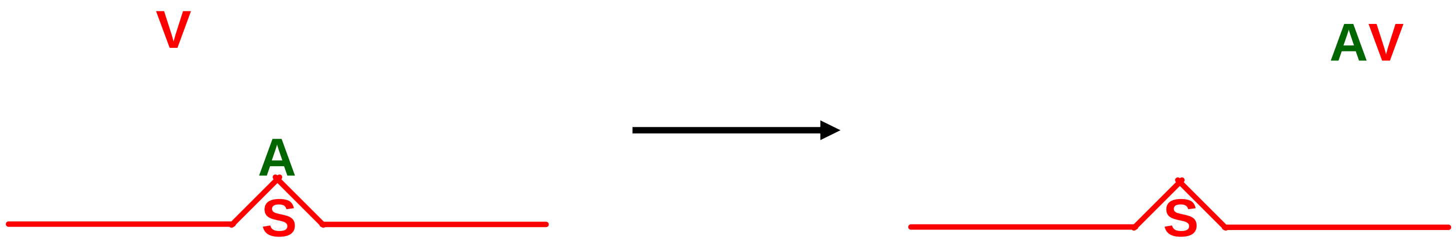


A + **S** ⟷ **AS**

Forward rate constant = k_A
Reverse rate constant = k_{-A}

Cobra Venom Reactions

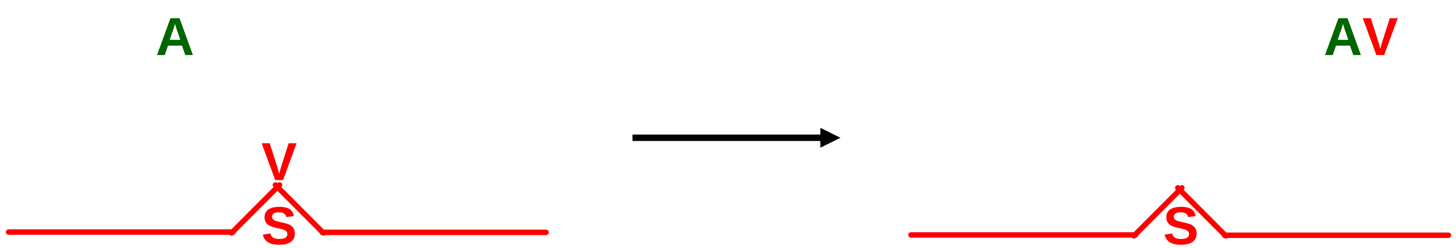
Reaction of venom with antivenom on site:



V + AS $\longrightarrow$ S + AV

Rate constant = k_{SA}

Reaction of antivenom with venom on site:



A + VS $\longrightarrow$ S + AV

Rate constant = k_{SV}

Cobra Venom Reactions

Reaction of venom and antivenom in blood:

$V + A \longrightarrow AV$ Rate constant = k_P

Removal of products and reactants from system:

$V \longrightarrow$ excreted Rate constant = k_{0V}

$A \longrightarrow$ excreted Rate constant = k_{0A}

$VA \longrightarrow$ excreted Rate constant = k_{0P}

Rate Law and Material Balances contd.

Concentration of venom in the blood

$$\frac{d(C_V)}{dt} = \begin{bmatrix} \text{initial concentration} \\ \text{of free sites} \end{bmatrix} \left(-\begin{bmatrix} \text{fraction of sites being} \\ \text{uncovered by venom} \end{bmatrix} + \begin{bmatrix} \text{fraction of sites already} \\ \text{covered by antivenom that} \\ \text{are reacting with venom} \end{bmatrix} \right) - \begin{bmatrix} \text{concentration of sites being occupied} \\ \text{by venom - antivenom reaction} \end{bmatrix} - \begin{bmatrix} \text{concentration of venom} \\ \text{leaving the body} \end{bmatrix}$$

$$\frac{d(C_V)}{dt} = C_{S0}\left(-k_V f_S C_V - k_{SA} f_{SA} C_V\right) - k_P C_V C_A - k_{OV} C_V$$

Rate Law and Material Balances contd.

Concentration of antivenom in the blood

$$\frac{d(C_A)}{dt} = \begin{bmatrix} \text{initial concentration} \\ \text{of free sites} \end{bmatrix} \left(-\begin{bmatrix} \text{fraction of sites being} \\ \text{covered by antivenom} \end{bmatrix} + \begin{bmatrix} \text{fraction of sites being} \\ \text{uncovered by antivenom} \end{bmatrix} \right)$$

$$+ \begin{bmatrix} \text{initial concentration} \\ \text{of free sites} \end{bmatrix} \left(-\begin{bmatrix} \text{fraction of sites already} \\ \text{covered by venom that are} \\ \text{reacting with antivenom} \end{bmatrix} \right)$$

$$- \begin{bmatrix} \text{concentration of sites being occupied} \\ \text{by venom - antivenom reaction} \end{bmatrix} - \begin{bmatrix} \text{concentration of venom} \\ \text{leaving the body} \end{bmatrix}$$

$$\frac{d(C_A)}{dt} = C_{S0}\left(-k_A f_S C_A + k_{-A} f_{SA} - k_{SV} f_{SV} C_A\right) - k_P C_V C_A - k_{OA} C_A$$

Base Case: Polymath Input

Indep Var: t
Initial Value: 0
Solve with: RKF45
Final Value: 0.5

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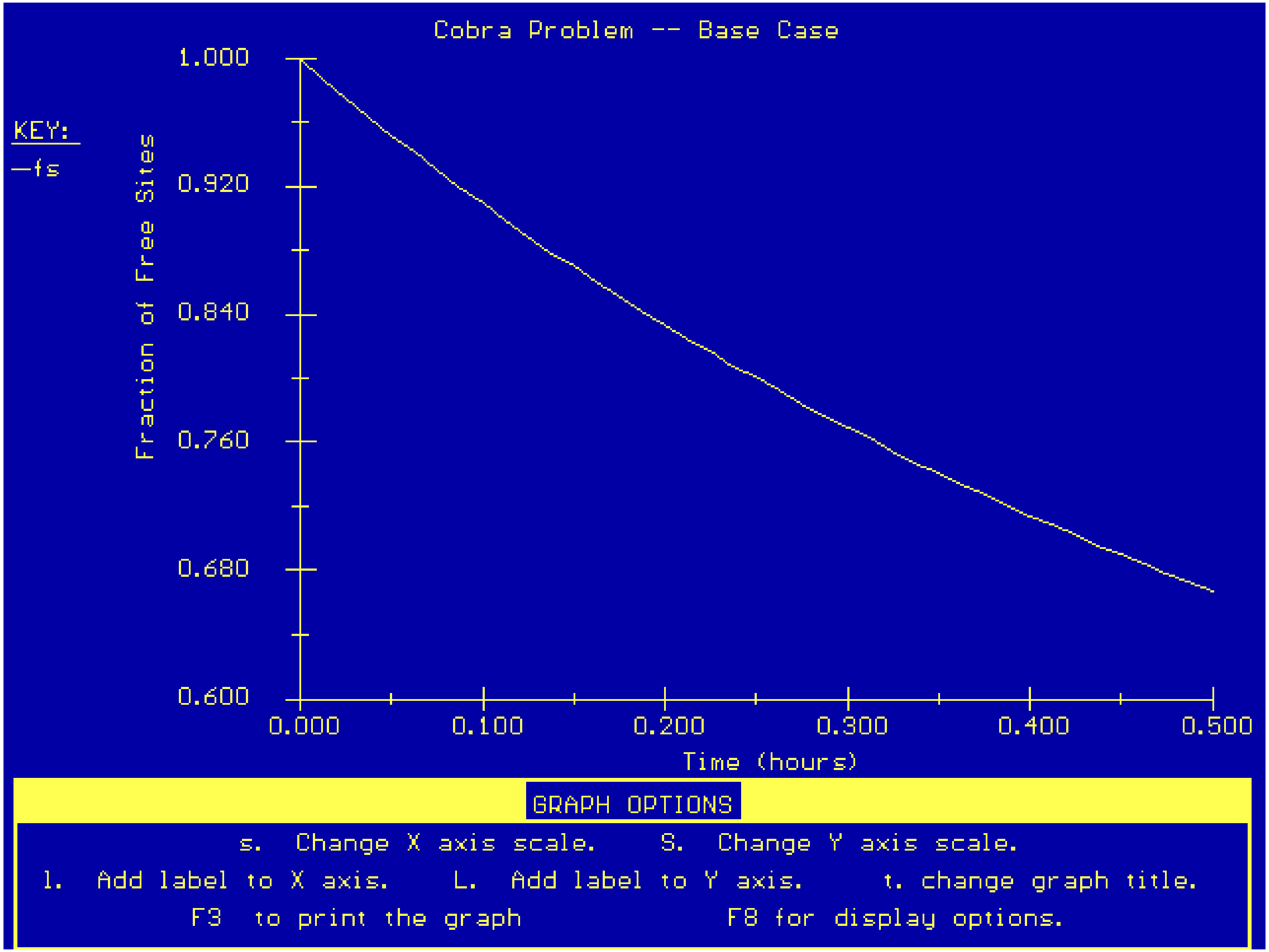
	Differential equations / explicit equations	Initial value
1	d(fsv)/d(t) = kv*fs*Cv-ksv*fsv*Ca	0
2	d(fs)/d(t) = -kv*fs*Cv-ka*fs*Ca+kia*fsa+g	1
3	d(Cv)/d(t) = Cso*(-kv*fs*Cv-ksa*fsa*Cv)+h	5e-09
4	d(Ca)/d(t) = Cso*(-ka*fs*Ca+kia*fsa)+j	0
5	d(fsa)/d(t) = ka*fs*Ca-kia*fsa-ksa*fsa*Cv	0
6	d(Cp)/d(t) = Cso*(ksv*fsv*Ca+ksa*fsa*Cv)+m	0
7	kv = 2e8	n.a.
8	ksv = 6e8	n.a.
9	ka = 2e8	n.a.
10	kia = 1	n.a.
11	Cso = 5e-9	n.a.
12	ksa = 6e8	n.a.
13	kp = 1.2e9	n.a.
14	kov = 0	n.a.
15	koa = 0.3	n.a.
16	kop = 0.3	n.a.
17	g = ksa*fsa*Cv+ksv*fsv*Ca	n.a.
18	h = -kp*Cv*Ca-kov*Cv	n.a.
19	m = kp*Cv*Ca-kop*Cp	n.a.
20	j = -Cso*ksv*fsv*Ca-kp*Cv*Ca-koa*Ca	n.a.

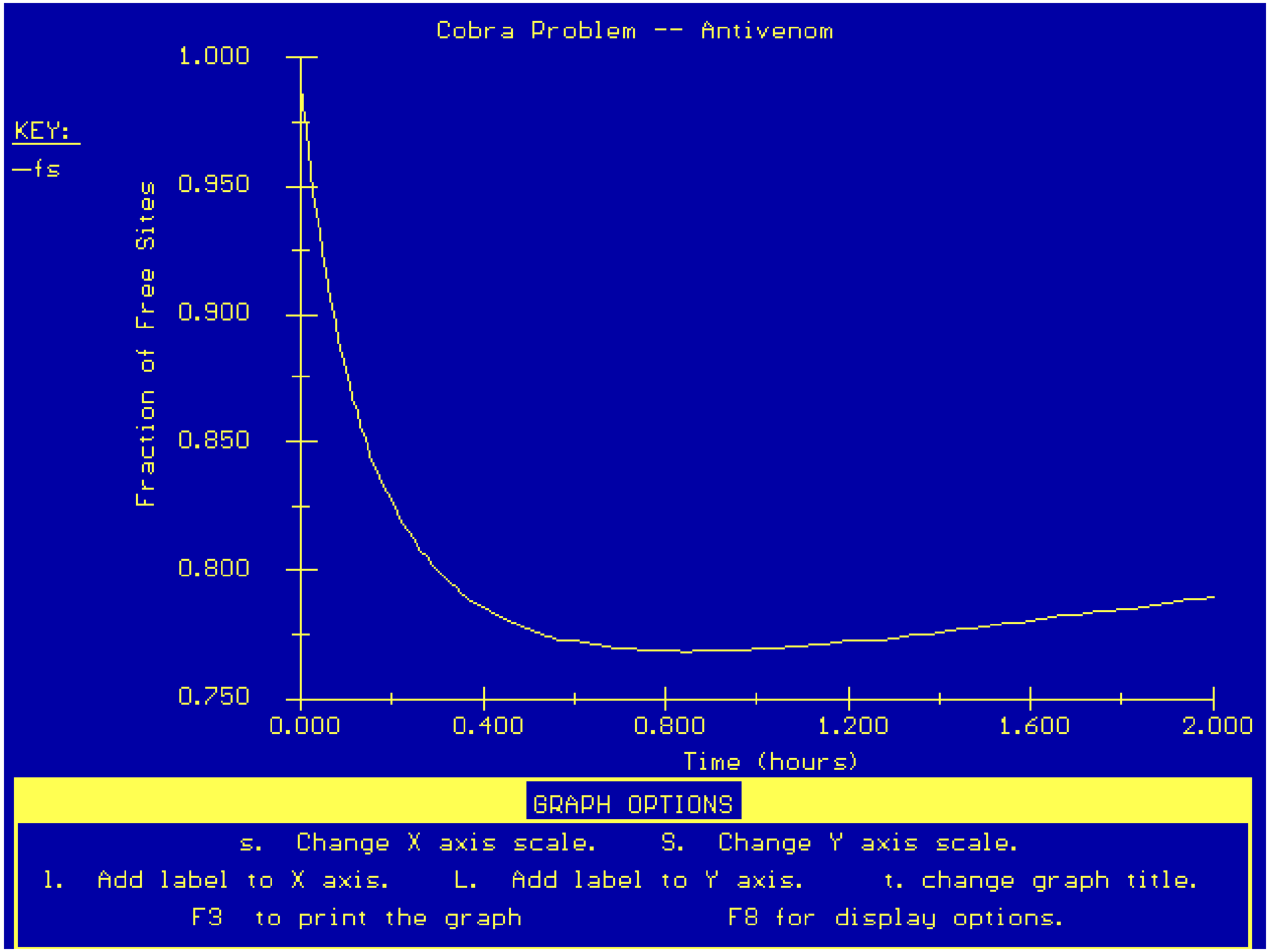
Assumptions:

1. Body is a batch reactor
2. Body is well-mixed

Polymath Solution for the Base Case



Polymath Solution for the Antivenom Case



Hippo

Modeling the Digestive System of a Hippopotamus*

Matthew Robertson, Fredrik Persson, Professor H. Scott Fogler

"Even hippo's like Chemical Reaction Engineering."

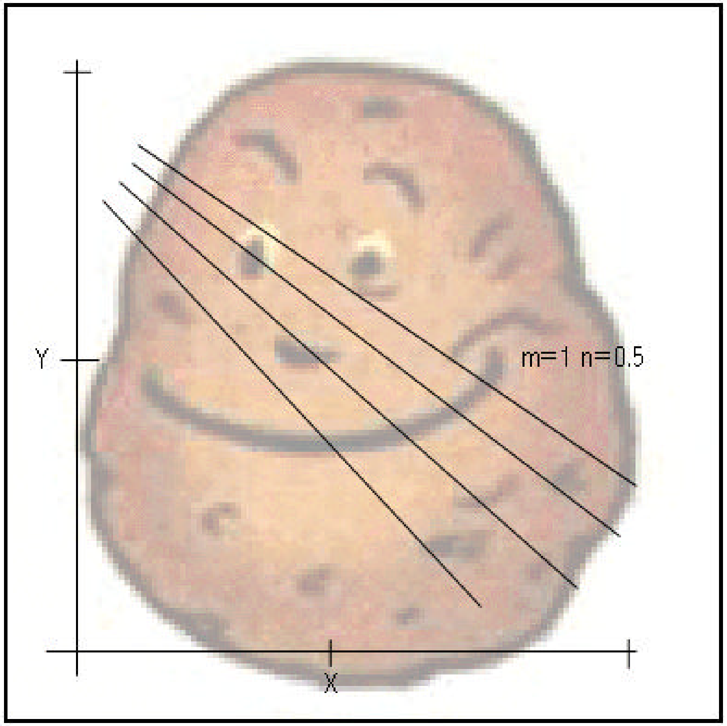
*From a problem suggested by **Professor Alice P. Gast**
["Animal Guts as Ideal Reactors", Chemical Engineering Education, Winter 1998, pp 24-29]

Potato

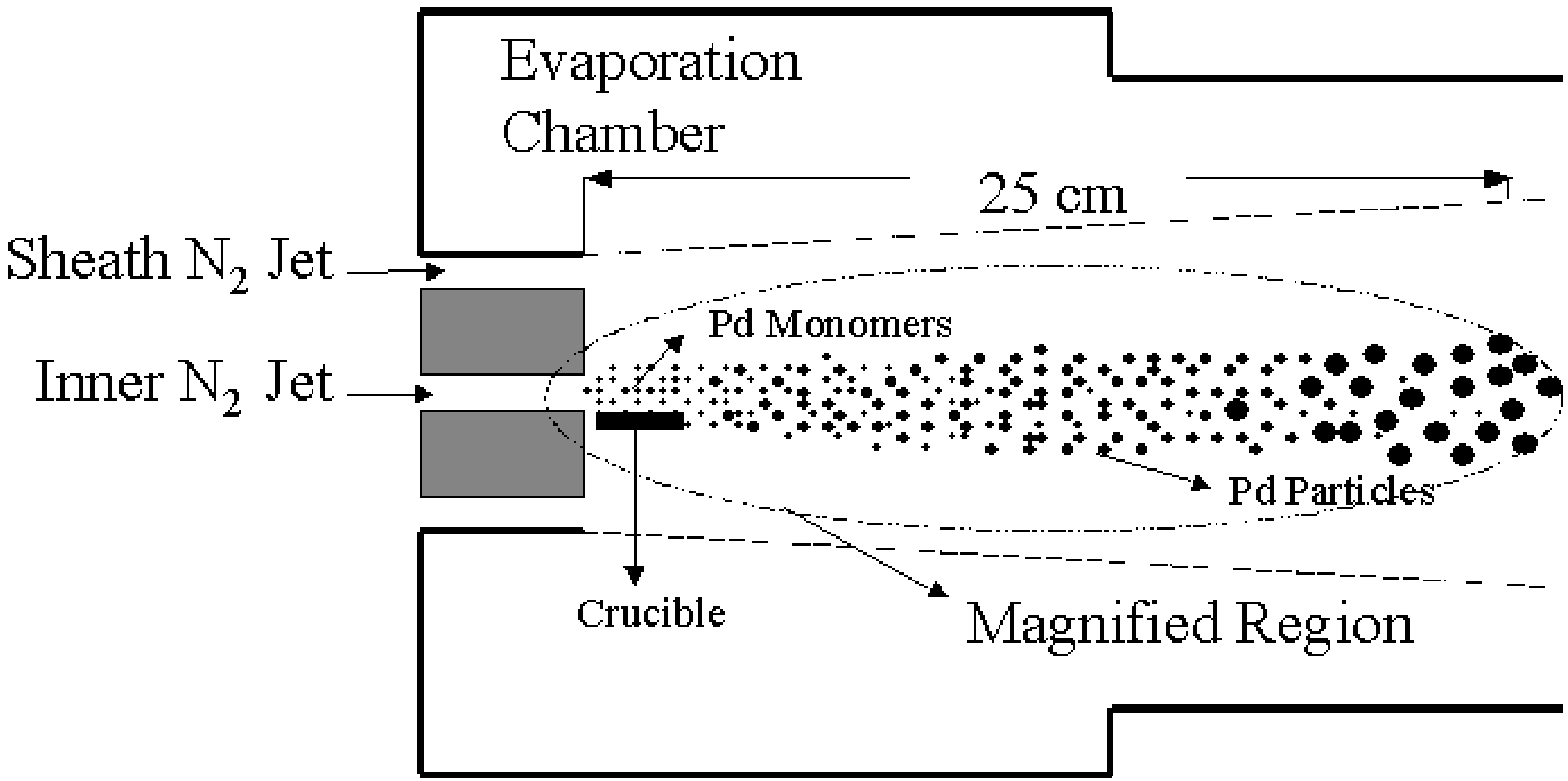
Baking a Potato!

A basic chemical engineering experiment by:

*Matthew Robertson, Fredrik Persson, Lander Coronado-Garcia,
Professor H Scott Fogler and Professor Levi Thompson*

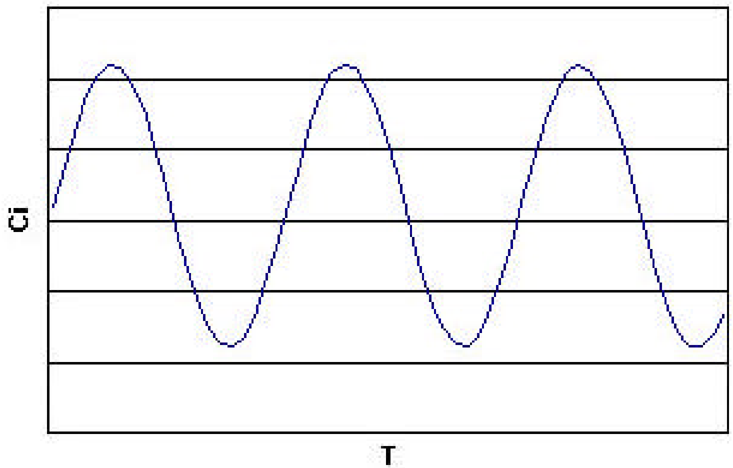


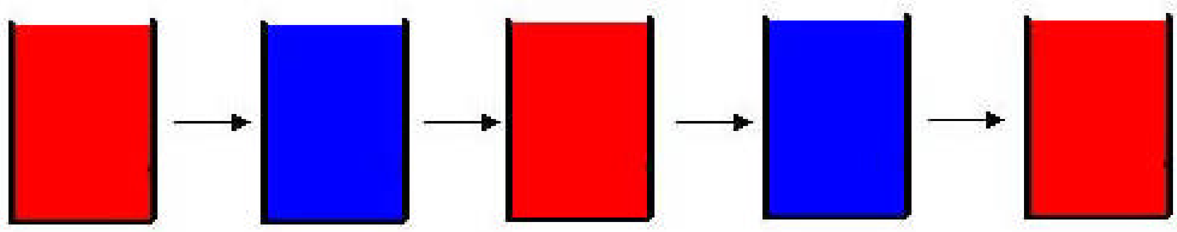
Aerosol Reactors



Oscillating Reactions

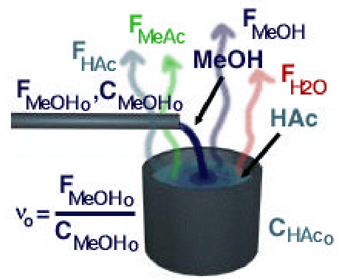
Oscillating Reactions Web Module





Reactive Distillation

Introduction



$$CH_3COOH + CH_3OH \rightleftharpoons CH_3COOCH_3 + H_2O$$

Acetic Acid, Methanol, Methyl Acetate, Water

Reactive distillation is used with **reversible**, **liquid phase** reactions. Suppose a reversible reaction had the following chemical equation :

$$A + B \rightleftharpoons C + D$$

For many revesible reactions the equilibrium point lies far to the left and little product is formed :

$$A + B \leftharpoondown\!\!\rightharpoonup C + D$$

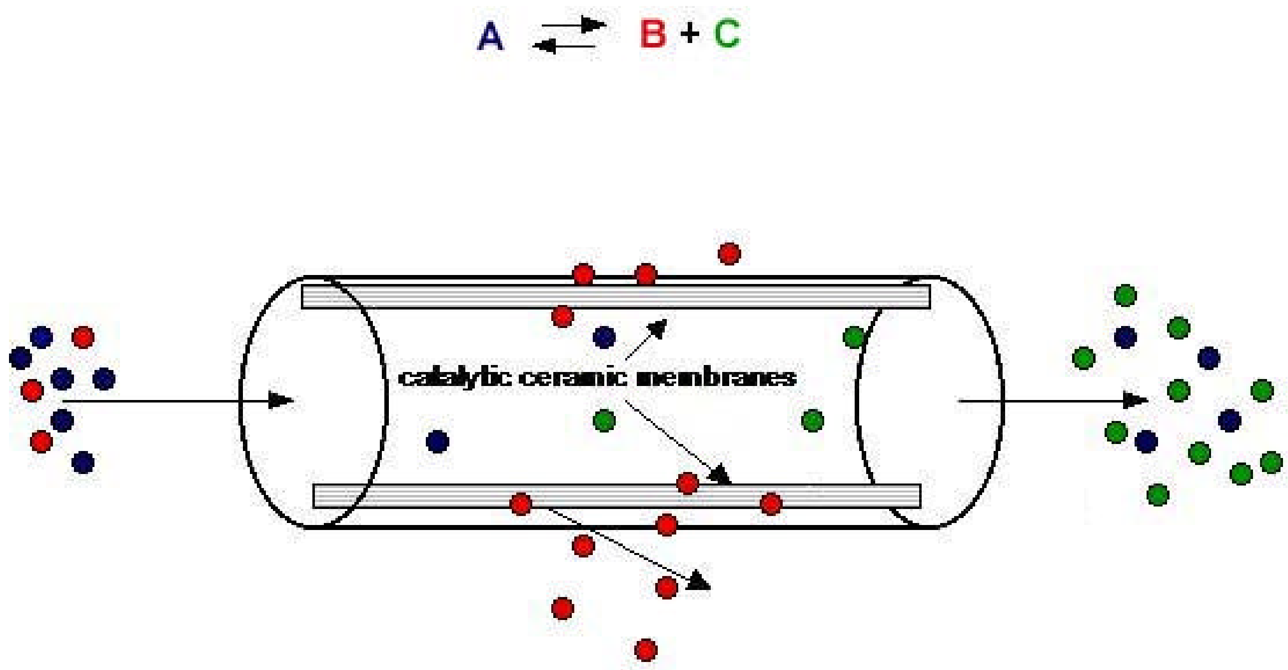
However, if one or more of the products are removed more of the product will be formed because of Le Chatlier's Principle :

$$A + B \rightleftharpoons C + D\uparrow$$

Removing one or more of the products is one of the principles behind reactive distillation. The reaction mixture is heated and the product(s) are boiled off. However, caution must be taken that the reactants won't boil off before the products.

For example, Reactive Distillation can be used in removing acetic acid from water. Acetic acid is the byproduct of several reactions and is very usefull in its own right. Derivatives of acetic acid are used in foods, pharmaceuticals, explosives, medicinals and solvents. It is also found in many homes in the form of vinegar. However, it is considered a polutant in waste water from a reaction and must be removed.

Membrane Reactors



A mixed feed of A and B enters the membrane reactor. C is produced in the reactor, and B diffuses out through the membrane pores. There are multiple ceramic membranes, but only two are shown for simplicity.

Creative Thinking

Elementary Principles of Chemical Processes, 3/e

- Felder and Rousseau

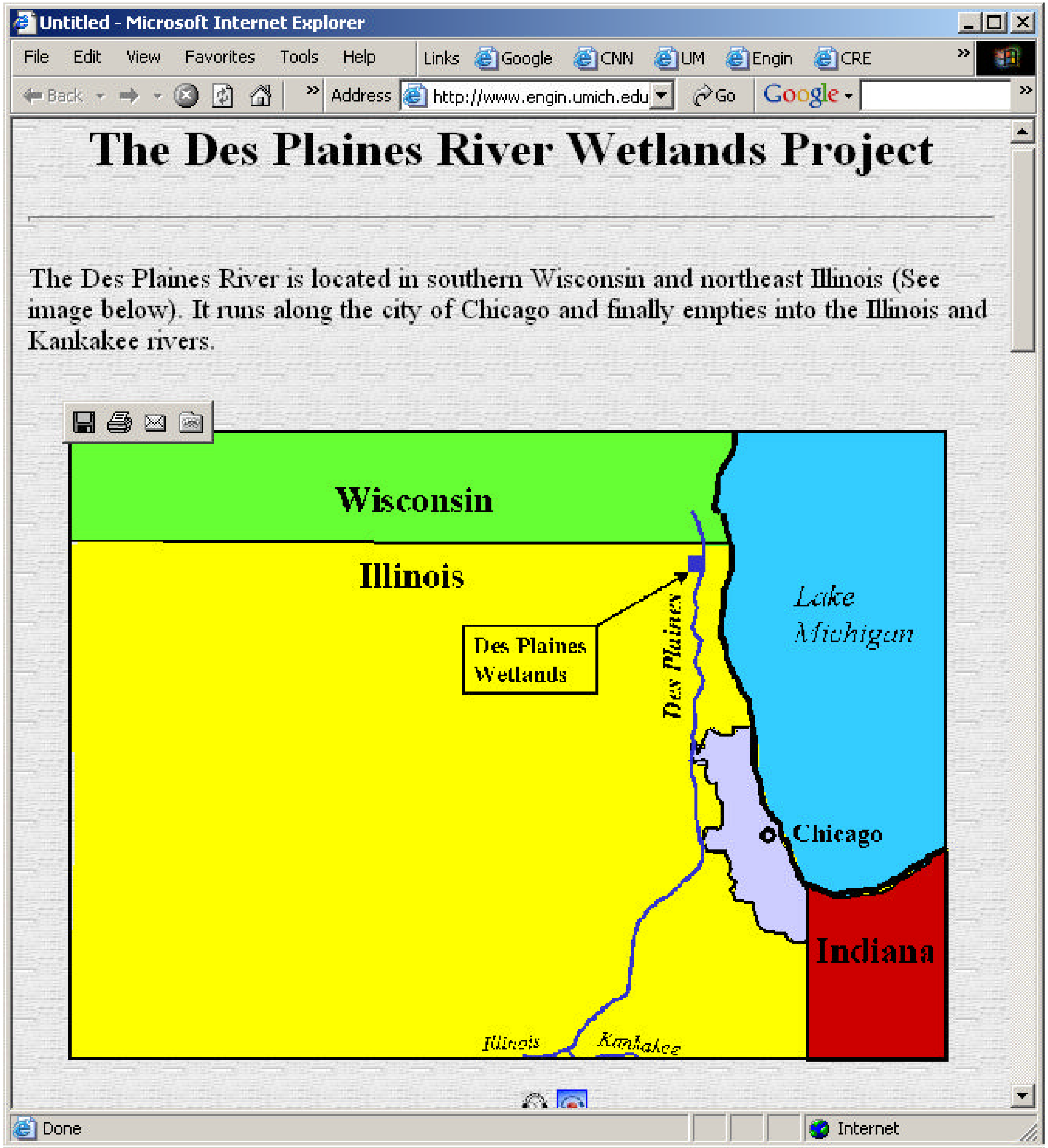
CREATIVITY EXERCISE

The costs of petroleum and natural gas have increased dramatically since the early 1970's, and there is some question about their continued long-term availability. List as many alternative energy sources as you can think of, being as creative as you can, and then go back and suggest possible drawbacks to each one.

Vehicles to Develop Creative Thinking Skills

"Thinking creatively is an active, purposeful, cognitive process we use to develop ideas that are unique, useful, and worthy of further elaboration."

- Techniques to develop creative ideas
- Solving Open-Ended Problems (OEPs)
- Solving OEP enhanced home problems
- Learning how to choose open ended problems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The Des Plaines River Wetlands Project
The Des Plaines River is located in southern Wisconsin and northeast Illinois (See image below). It runs along the city of Chicago and finally empties into the Illinois and Kankakee rivers.
Wisconsin
Illinois
Lake Michigan
Des Plaines Wetlands
Des Plaines
Chicago
Indiana
Illinois
Kankakee
Done
Internet

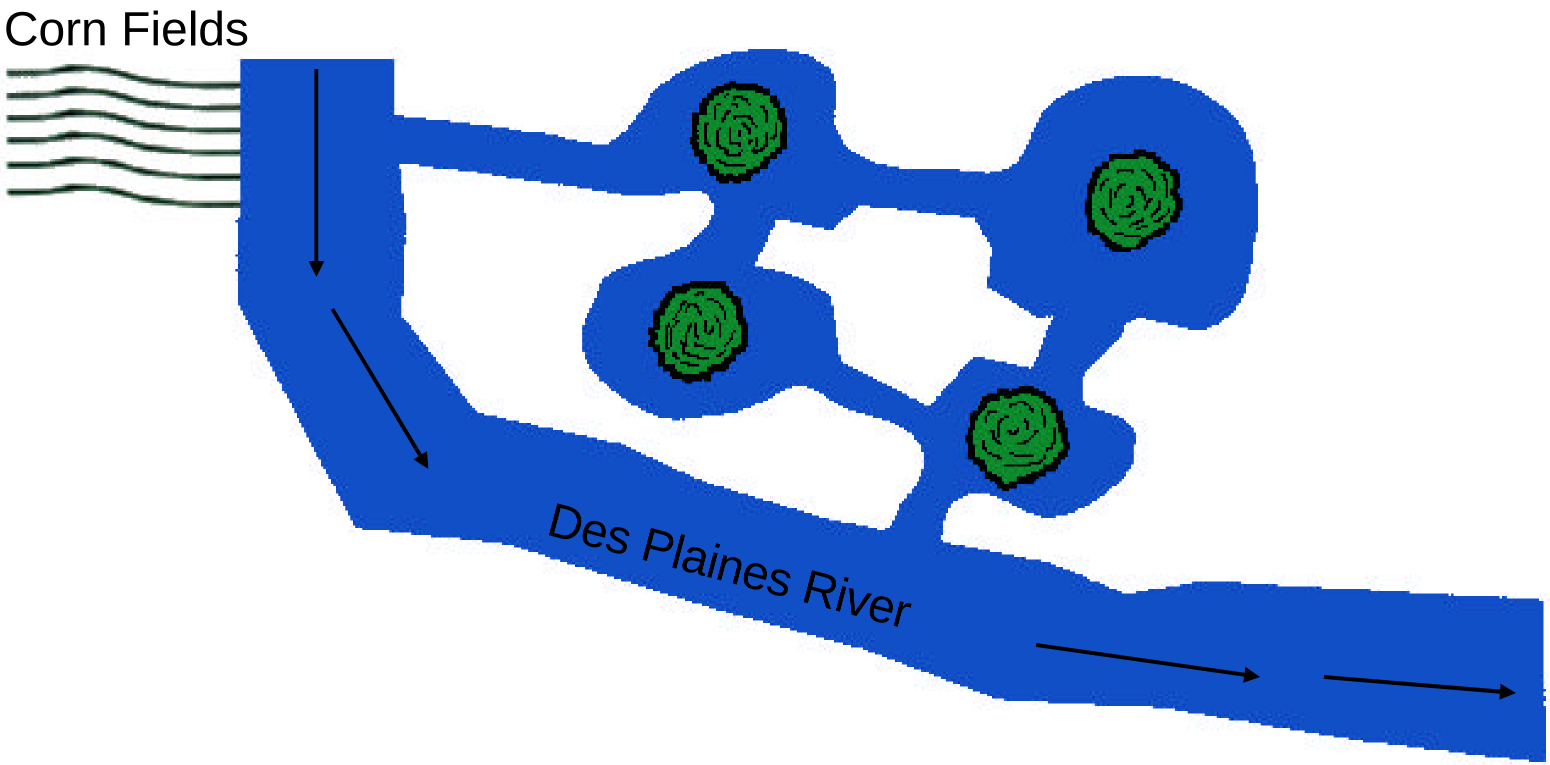
Des Plaines River Wetlands

Des Plaines River Wetlands

Des Plaines River Wetlands

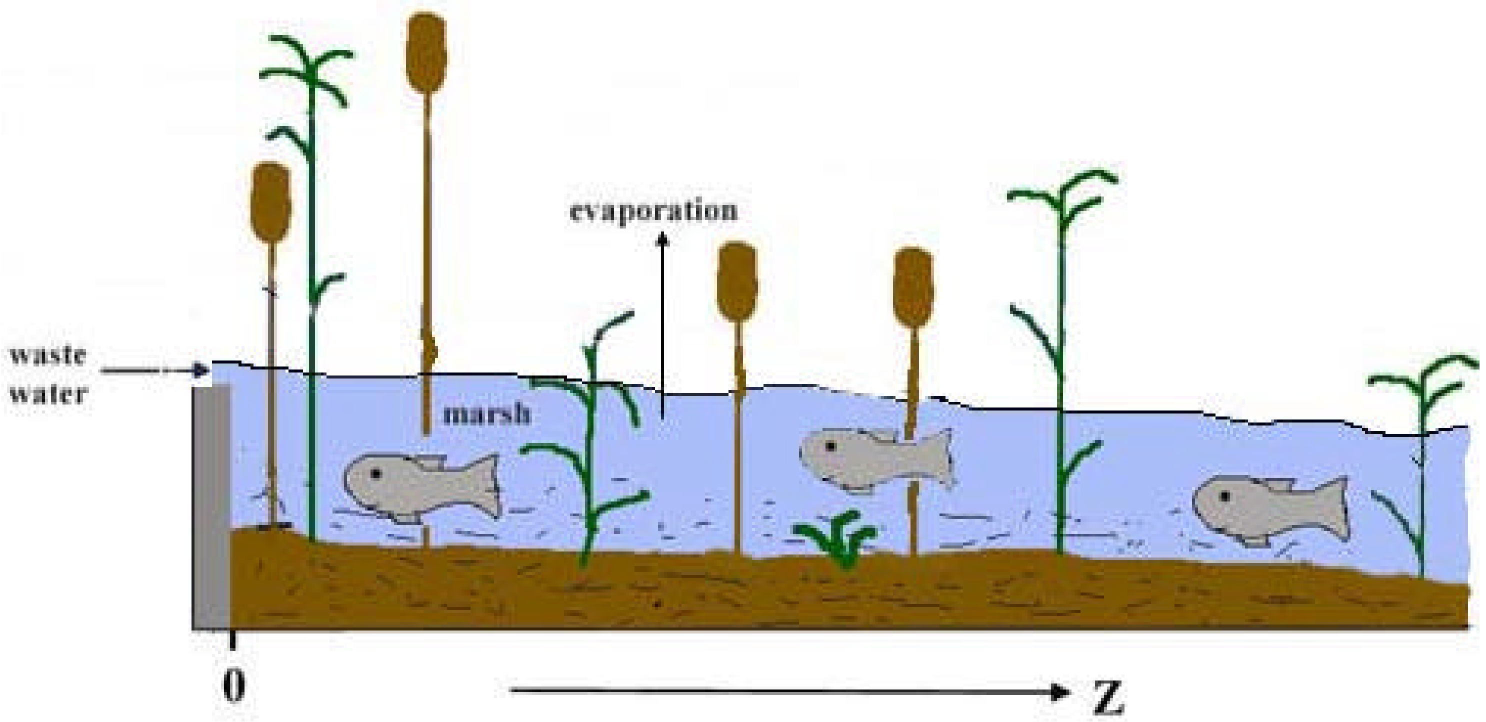
Wetlands to degrade Atrazine

$$A \xrightarrow{k_1} \text{Products}$$



Des Plaines River Wetlands

Modeling a Treatment Wetland as a simple PFR



The Equations

Wetlands

Mole Balance

$$F_{A0}\frac{dX}{dV} = -r_A \qquad (1)$$

Rate Law

$$-r_A = k_1 C_A \qquad (2)$$

Stoichiometry

$$u = u_o + \frac{Q*W*z}{r_m} \qquad (3)$$

$$C_A = \frac{F_{A0}}{u} \qquad (4)$$

Combine

$$C_{A0} = \frac{C_{A0}(1-X)}{1-\dfrac{Q*W*z}{r_m*u_o}} \qquad (5)$$

Solve

$$X(z) = 1-\left(1-\frac{Q*W*z}{r_m*u_o}\right)^{\left(\frac{1}{\frac{Q*W}{r_m*u_0}}*k_1*W*\frac{D}{u_o}\right)} \qquad (6)$$

CACHE

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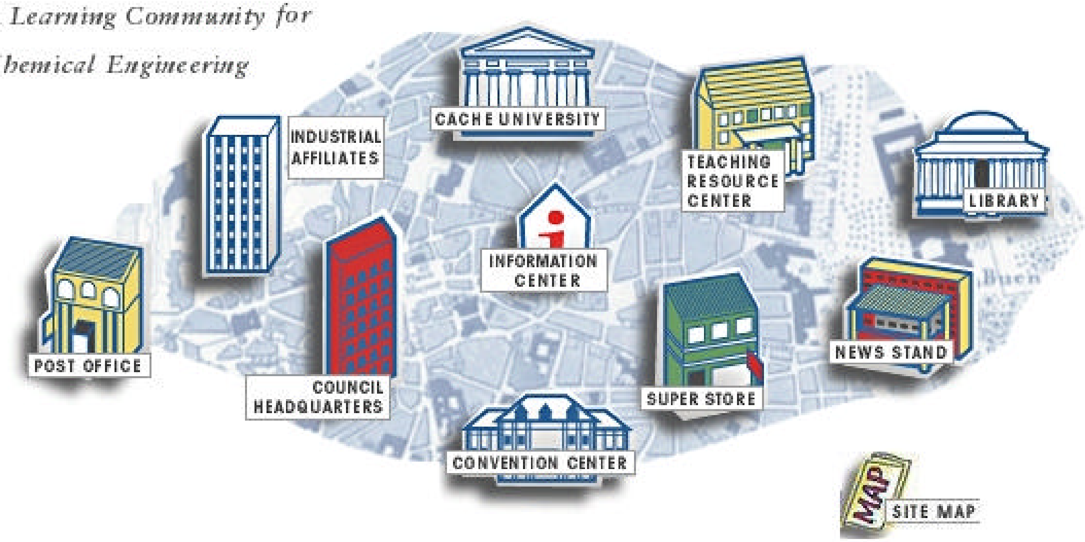
A Learning Community for Chemical Engineering



Map key

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Chemical Engineering Faculty Openings

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