Elements of Chemical Reaction Engineering 7th edition Fogler Solutions Manual

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Solutions Manual for

Elements of Chemical Reaction Engineering

Seventh Edition

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Solutions to Chapter 19 – Electrochemical Reactor Design
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WEB HOME PAGE

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Lecture Notes

Software

Undergraduate (ChE 344) Homepage

Graduate (ChE 528) Homepage

Asychronous Learning

Additional Textbook Websites

Additional Resources

SafeChemE Website

Interactive Computer Games

Web Modules

Thoughts on Problem Solving

FAQs

Fun YouTube Videos

Updates and Typos

Interactive Computer Games (ICGs)

The Interactive Computer Games (ICGs) listed below arecontained on the*website below.* Game players can click on the Run from the website link to begin play each ICG title. Note that there will be a pa.Jsewhlle the game is loaded tromour servers. Alternately, one can use the Install to PC link to install each g.:rne on the PC. This installation will typically instaJl an icon on the desktop, Please take the default location 1orthe Installation files. Detailed instructions for installing and using the ICGs are available.

As these interactive games are played, the player will t>e asked a number of questions related to thecorresponding material in the textbook, The computer will keep track of all the correct answers and at the end of the game will displaYa roded *performance number* that reflects how well the player mastered the materiaJin the text. Instructors will havea manual to decode the performre,ce number.

Note: The Interactive ComputerGames may NOT work onoximately 10% of Windows machines. We can't find aspecific reason, so if it doesn't work, pleasetry th911on a different Windows computer.



Kinetics Challenge I (InstaJI to PC, InstaJlatlon Instructions)
Oul2 Show
Introduction to Kinetics
DescriP-tion of the Module
Ol>lectlves for Chapter One

Staging (Install to PC, Installation Instructions)
Reactor Sequencing Optimization
DescriotlonoJ the Module
Oofectlves tor Chapter Two

Kinetics Challenge II (Install to PG, Installation Instructions)
Oul2Show
Stoichiometry and Rate Laws
DescriP-tion of the Module
Obfectlves for Chapter Four

r-h..Jrder Mystery(Install to PC, Installation Instructions)
CSTR Volume Algorithm
Descriptionof the Module
Oofectlves for G.b gpter Five

Tic Tac Toe(Install to PC, Installation Instructions)
Isothermal Reactor Design: Ergun, Arrhenius, and Van't Hoff Equations
DescrlP-tlonof the Module
Oofectlves for Chapter Six

Ecology A Wetlands Protllem (Install to PC, Installation Instructions)
Collection and Analysis of Rate Date: Ecological Engineering
DescriP-tion of the Module
Oofectlves for Chapter Seven

Great Race (Install to PC, Installation Instructions)
Multiple Reactions
DescriP-tlonof the Module
Oofectlves for ChaPl.Sl:: fi Q.O!

Enzyme Man (Install to PC, Installation Instructions I
Enzyme Kinetics
DescrlP-tlonof the Module
Ol>lectlves for Chapter Nine

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INTERACTIVE COMPUTER GAMES (ICGs)

Heterogeneous Catalysis [InstaJIto PC, InstaJlatlon Instructions)
Catalytic Rate Equatlons,Status:Alpha Release
Warning: This module is not tullytested. You may encounter abnormal behavior.
Descriptionof the Module
Ol>lectIves for Chapter Ten

Heat Effects 1 (Install to PC,Installatlon Instructions)
Basketbal Challenge
Mole and Energy Balances In a CSTR
DescrIP-tlonof the Module
Oofectlves for Chapter Thirteen

Heat Effects *2* (Install to PC, Installation Instructions)
Effect of Parameter Variation on a PFR
Mole end Energy Balances In e PFR,Stetus: Alpha Release
Warning: This module is not tullytested. You may encounter abnormal behavior.
DescriptlonoI the Module
Oofectlves tor chapter Thlrteen

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Interactive Computer Games (ICGs)

Kinetic Challenge 1

Kinetics Challenge 1 -- Quiz Show	
Concepts	Definitions of rates of reactions. Types of reactors. General mole balances for batch reactors, CSTR's and PFR's.
Time	29 minutes ± 10 minutes
Reference	Fogler: Chapter 1
Description	This game allows students to test their knowledge about general mole balance equations, reaction rate laws, and different types of reactions and reactors. Individual students will find themselves going head-to-head against computer opponents in an interactive game with timed responses. Twenty multiple-choice questions are selected from a pool of approximately 100 possible questions, so the game will be different every time. The questions fall under four main categories: mole balance, reactions, rate laws, and reactor types; and there are five difficulty levels within each category. Each correct answer will earn the student a given number of points; the more difficult the question, the higher the point values.



The student has 25 seconds to choose the correct answer. The module responds to the student's choice, either reinforcing the reasoning for a correct answer, or immediately clarifying a misunderstanding if an incorrect answer is entered. If no response is entered within the time limit, or if an incorrect response is entered, the points are lost, and one of the computer competitors tries to answer the question:



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LIVING EXAMPLE PROBLEMS (LEPs)

Chapter 12: Steady-State Nonisothermal Reactor Design: Flow Reactors with Heat Exchange

Living Example Problems

The following examples can be accessed with Polymath™, MATLAB™, or Wolfram CDF Player™.

Living Example Problem	Polymath™ Code	Matlab Code	Wolfram CDF Code	AspenTech ™
Example 12-1 Isomerization of Normal Butane with Heat Exchanger	a) Co-current: LEP-12-1a.pol b) Countercurrent: LEP-12-1b.pol c) Constant T_a: LEP-12-1c.pol d) Adiabatic: LEP-12-1d.pol	a) Co-current: LEP-12-1a.zip b) Countercurrent: LEP-12-1b.zip c) Constant T_a: LEP-12-1c.zip d) Adiabatic: LEP-12-1d.zip	a) Co-current: LEP-12-1a.cdf b) Countercurrent: LEP-12-1b.cdf c) Constant T_a: LEP-12-1c.cdf d) Adiabatic: LEP-12-1d.cdf	--
Example 12-2 Production of Acetic Anhydride	a) Adiabatic: LEP-12-2a.pol b) Constant T_a: LEP-12-2b.pol c) Co-current LEP-12-2c.pol d) Countercurrent: LEP-12-2d.pol	a) Adiabatic: LEP-12-2a.zip b) Constant T_a: LEP-12-2b.zip c) Co-current: LEP-12-2c.zip d) Countercurrent: LEP-12-2d.zip	a) Adiabatic: LEP-12-2a.cdf b) Constant T_a: LEP-12-2b.cdf c) Co-current: LEP-12-2c.cdf d) Countercurrent: LEP-12-2d.cdf	a) Adiabatic: Tutorial, ASPEN Backup File b) Constant Heat Exchange: Tutorial, ASPEN Backup File
Example 12-3 Production of Propylene Glycol in an Adiabatic CSTR	--	--	LEP-12-3.cdf	--
Example 12-4 CSTR with a Cooling Coil	LEP-12-4.pol	LEP-12-4.zip	LEP-12-4.cdf	--
Example 12-5 Parallel Reaction in a PFR with Heat Effects	LEP-12-5.pol	LEP-12-5.zip	LEP-12-5.cdf	--
Example 12-6 Multiple Reactions in a CSTR	LEP-12-6.pol Alternative Solution: LEP-12-6a.pol	LEP-12-6.zip	LEP-12-6.cdf	--
Example 12-7 Complex Reactions	a) Co-current: LEP-12-7a.pol b) Countercurrent: LEP-12-7b.pol c) Constant T_a:LEP-12-7c.pol d) Adiabatic: LEP-12-7d.pol	a) Co-current: LEP-12-7a.zip b) Countercurrent: LEP-12-7b.zip c) Constant T_a:LEP-12-7c.zip d) Adiabatic: LEP-12-7d.zip	a) Co-current: LEP-12-7a.cdf b) Countercurrent: LEP-12-7b.cdf c) Constant T_a:LEP-12-7c.cdf d) Adiabatic: LEP-12-7d.cdf	--
Example R12-1 Industrial Oxidation of SO_2	LEP-RE12-1.pol	LEP-RE12-1.zip	--	--
Example 12-T12-3 PBR with Variable Coolant Temperature	LEP-T12-3.pol	LEP-T12-3.zip	LEP-T12-3.cdf	--
Example Lecture 19 A=B Adiabatic	Adiabatic A=B.pol	---	Adiabatic A=B.cdf	--

Wolfram and Python can be downloaded and installed on your computer free of charge

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ALGORITHM TO DECODE ICGs

**** CONFIDENTIAL ****

UNIVERSITY OF MICHIGAN
INTERACTIVE COMPUTER MODULES FOR CHEMICAL ENGINEERING
CHEMICAL REACTION ENGINEERING MODULES

H. Scott Fogler, Project Director

M. Nihat Gürmen, Project Manager (2002-2004)
Susan Montgomery, Project Manager (1991-1993)

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INTERPRETATION OF PERFORMANCE NUMBERS

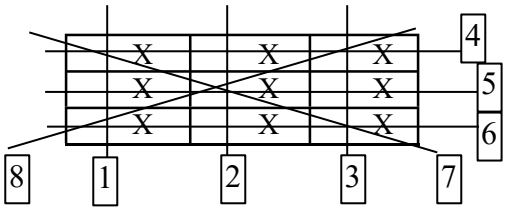
Students should record their Performance Number for each program, along with the name of the program, and turn it in to the instructor. The Performance Number for each program is decoded as described in the following pages.

Please report problems to icm.support@umich.edu.

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ICMs with Windows® interface

Module	Format	Interpretation	Example
KINETIC CHALLENGE I			
	CzBzzAzz	Score = 1.5 * AB.C z = random numbers Note: 75% constitutes mastery.	Perf. No. = **7**52**4**1**6**92 Score = 1.5*(62.7) = 94 %
KINETIC CHALLENGE II			
	CzBzzAzz	Score = 2.0 * AB.C z = random numbers Note: 75% constitutes mastery.	Perf. No. = **0**3**7**76**4**67 Score = 2.0*(47.0) = 94 %
MURDER MYSTERY			
	zzAzz	A even: Killer and victim correctly identified A odd: Killer and victim not identified z = random numbers Note: An even number for the middle digit constitutes mastery.	Perf. No. = 50**7**32 Score: No credit
TIC TAC TOE			
	zDzCzBzA	Score = 4.0 * AB.C z = random numbers Configurations	Perf. No. = 77803581 Score = 4*(15.0) = 60 configuration 7 completed



Note: Student receives 20 points for every square answered correctly.
A score of 60 is needed for mastery of this module.

GREAT RACE			
	zzzCzABz	Score = 6.0 * AB.C z = random numbers Note: A score of 40 is needed for mastery of this module.	Perf. No. = 77738078 Score = 6*(07.3) = 44

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ECOLOGY

AzBCzaaD **z = random numbers**
a = random characters

A gives info on r^2 value of the student's linearized plot
A=Y if r^2 >= 0.9
A=A if 0.9 > r^2 >= 0.8
A=X if 0.8 > r^2 >= 0.7
A=F if 0.7 > r^2
A=Q if Wetland Analysis/Simulator portion has not been completed

B gives info on alpha
B=1 to 4 => student's alpha < (simulator's alpha ± 0.5)
B=5 to 9 => student's alpha > (simulator's alpha ± 0.5)
B=X if Wetland Analysis/Simulator portion has not been completed

C indicates number of data points deactivated during analysis
C=number of deactivated data points if at least 1 point has been deactivated
C=a randomly generated letter from A to Y if 0 points deactivated
C=Z if Wetland Analysis/Simulator portion has not been completed

D gives info on solution method used by student
D=1 if polynomial regression was used
D=2 if differential formulas were used
D=3 if graphical differentiation was used
D=4 to 9 if Wetland Analysis/Simulator portion has not been completed

Perf No. = A7213DF2
1) A => 0.9 > r^2 >= 0.8
2) 2 => student's alpha < (simulator's alpha ± 0.5)
3) 1 => one data point was deactivated
4) 2 => differential formulas were used

STAGING

zCBzAFzED **z = random numbers** Perf. No. = 2**12**5**4**8**2**9**13**

Final conversion = 2*AB.C conversion = 2*42.1 = 84.2
Final flow rate = 2*DE.F flow rate = 2*31.2 = 62.4

Please make a pass/fail criterion based on these values.

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ICMs with Dos® interface

Module	Format	Interpretation	Example
HETCAT			
	zzABzCD	A=2,3,5,7: interaction done B=2,3,5,7: intro done C=2,3,5,7: review done D denotes how much they did in the interaction: D<2 2 < D:5 4 4 < D:5 6 6<D z = random numbers	Perf. No. = 80**27**4**35** A: Worked on interaction B: Looked at intro C: Looked at review D: found parameter values, didn't find mechanism Not done Dependences Parameter values Mechanism
	Note: Performance number given only if student goes through the interaction portion of the module		
HEATFX1			
	zzAzz	A even: score > 85 % z = random numbers	Perf. No. = 53**6**07 Score > 85 %
	Note: Student told they have achieved mastery if their score is greater than 85%		
HEATFX2			
	zzzAzz	A even: completed interaction z = random numbers	Perf. No. = 407**5**82 Interaction not completed
	Note: Performance number given only if student goes through the interaction portion of the module.		

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SAMPLE COURSE SYLLABUS

ChE 344: CHEMICAL REACTION ENGINEERING

Fundamentals of chemical reaction engineering. Rate laws, kinetics, and mechanisms of homogeneous and heterogeneous reactions. Analysis of rate data, multiple reactions, heat effects, bioreactors. Design of industrial reactors.

Prerequisite: ChE 330, ChE 342

Fall
Lectures: M,W 8:40 (Sharp) to 10:30 (not so sharp) – Room: 1013 Dow

Instructor:
Professor Bryan R. Goldsmith
3168 Dow, bgoldsm@umich.edu
Office Hours: M,W 10:30a to 11:30a
Course assistants include: Instructional aids, tutor, proctors, and graders

Text Required
Elements of Chemical Reaction Engineering, 7th edition, H. Scott Fogler
Web sites: Chemical Reaction Engineering, *http://www.umich.edu/~elements/7e/index.html*
Process Safety Across the Chemical Engineering Curriculum, *http://umich.edu/~safeche/*

Recommended Reading List
- *Problem Solving in Chemical and Biochemical Engineering with POLYMATH, Excel, and MATLAB*, 2nd Edition 2008, Cutlip & Shacham
- *The Elements of Style*, Strunk and White
- *Strategies for Creative Problem Solving*, 3rd Edition 2014, Fogler, LeBlanc & Rizzo (for OEP's)

Schedule
Note - all ICGs (Interactive Computer Games) are Individual

1) Wednesday, September 9

Topic:	Lecture 1 – Chapter 1, Introduction, POLYMATH, MATLAB, Wolfram and Polymath, Mole balances Intro to LearnChemE – view one LearnChemE video of your choice
Read:	Introduction, Appendix B
In-Class Problem:	No In-Class Problem

2) Monday, September 14

Topic:	Lecture 2 – Chapter 2, Design equations, Levenspiel plots, Reactor staging
Read:	Chapter 1, P1-9$_A$, Appendix A, from the Web Chapter 2, Sections 2.1, 2.2, and 2.3
Hand In:	Problem Set 1: Q1-1$_A$, Q1-2 $_A$ Do five i>clicker questions, P1-1$_A$ only use Wolfram or Python, P1-3$_B$, P1-5$_A$, Q2-1$_A$, Q2-2 $_A$
In-Class Problem:	1
Study Problems:	P1-6$_A$ (a) and (c), P1-8$_A$ Note: Study problems have found their way many times on exams

3) Wednesday, September 16

Topic:	Lecture 3 – Chapter 3, Rate laws
Read:	Chapter 2, Chapter 3
Hand In:	Problem Set 2: P2-2$_A$ (a), (d) and (g), Q3-1$_A$, Q3-2 $_A$ Do five i>clicker questions.
In-Class Problem:	2, P3-9$_B$ (*Hint:* Viewing the University of Alabama YouTube video "The Black Widow" may help you with today's in class problem)
Study Problems:	P2-7$_A$

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4) Monday, September 21

Topic:	Lecture 4 – Chapter 4, Stoichiometry Batch Systems
Read:	Chapter 4 Section 4.1
Hand In:	Problem Set 3: P2-10$_B$, P3-6$_A$, P3-12$_B$, P3-14$_A$, Q4-1$_A$, Q4-2 $_A$ Do five i>clicker questions
In-Class Problem:	3 - Bring i>clickers (tentative)
Study Problems:	P3-15$_A$

5) Wednesday, September 23

Topic:	Lecture 5 – Chapter 4, Stoichiometry Flow Systems
Read:	Chapter 4, Section 4.1
Hand In:	Problem Set 4: P4-2$_A$ (ICG)
In-Class Problem:	4
Study Problems:	Q4-3$_A$, Q4-4$_B$, Q4-5$_B$, Q4-6$_A$, Q4-9$_A$

6) Monday, September 28

Topic:	Lecture 6 – Chapter 5, Isothermal reactor design
Read:	Chapter 5, Chapter 5 Summary Notes on the Web site
Hand In:	Problem Set 5: P4-1$_A$ (a) and (b) only use Wolfram or Python, P4-3$_A$, P4-4$_B$, P4-5$_B$
In-Class Problem:	5
Study Problems:	P4-9$_B$, P4-10$_B$, P4-13$_C$

7) Wednesday, September 30

Topic:	Lecture 7 – Chapter 5, California Registration Exam Problem
Hand In:	Problem Set 6: Q5-1$_A$, Q5-2 $_A$ Do five i>clicker questions, Q5-10$_A$, Q5-11$_A$, Q5-12$_A$, Q5-13$_A$; P5-2$_A$, What are you asked to find P5-18$_B$? What is the Ergun Equation?
In-Class Problem:	6
Study Problems:	P5-1$_B$ (a) only use Wolfram or Python

8) Monday, October 5

Topic:	Lecture 8 – Chapter 5, Pressure drop
Read:	Chapter 5, Sections 5.4 and 5.5
Hand In:	Problem Set 7: P5-1$_A$ (b), (c) only use Wolfram or Python, P5-3$_A$, P5-4$_B$, P5-5$_A$, P5-8$_B$, P5-13$_B$, P5-16$_B$
In-Class Problem:	7 – Bring Laptops
Study Problems:	P5-9$_A$, P5-10$_B$

9) Wednesday, October 7

Topic:	Lecture 9 – Chapter 6, Membrane Reactors
Read:	Chapter 6
Hand In:	Problem Set 8: P5-22$_A$, Q6-1$_A$, Q6-2 $_A$ Do five i>clicker questions
In-Class Problem:	8 – Bring Laptops
Study Problems:	P5-21$_B$

10) Monday, October 12

Topic:	Lecture 10 – Chapter 6, Semibatch Reactors
Read:	Chapter 6
Hand In:	Problem Set 9: P5-1$_A$ (d), (e) and (f) only use Wolfram or Python, P5-11$_B$, P6-4$_B$, P6-5$_B$
In-Class Problem:	9 – Bring Laptops to carry out Polymath ODE Solver
Study Problems:	P6-7$_B$

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11) Wednesday, October 14

Topic:	Lecture 11 – Chapter 7, Analysis of Rate Data/Chapter 9, Pseudo Steady State
Read:	Chapter 7, Chapter 9, Section 9.1 and the cobra web module
Hand In:	Problem Set 10: P6-1_B (a) and (b) only use Wolfram or Python, P6-2_B (ICG), P6-11_B omit part (c), Q7-1_A, Q7-2_A Do five i>clicker questions
In-Class Problem:	10 – Bring Laptops to carry out Polymath Regression
Study Problems:	P7-7_B

12) Monday, October 19

Topic:	*No Classes – Fall Study Break*

13) Wednesday, October 21

Topic:	Lecture 12 – Chapter 8, Multiple Reactions
Read:	Chapter 8, Sections 8.1, 8.2, 8.3 and 8.4
Hand In:	Problem Set 11: P7-6_A, P7-9_A, Q8-1_A, Q8-2_A Do five i>clicker questions
In-Class Problem:	11
Study Problems	P7-11_A

14) Monday, October 26

Topic:	Lecture 13 – EXAM I – Covers Chapters 1 through 7 Closed book, web, notes, in-class problems and home problems

15) Wednesday, October 28

Topic:	Lecture 14 – Chapter 8: Multiple Reactions
Read:	Chapter 8, Sections 8.5, 8.6, 8.7 and 8.8
In-Class Problem:	12 – Bring Laptops
Hand In:	Problem Set 12: P8-1_A (a), (b) and (c) only use Wolfram or Python, P8-2_B (ICG), P8-5_B, P8-6_B, P8-7_C (a), (b) and (c), P8-16_B (a) and (b)
Study Problems	P8-10_B

16) Monday, November 2

Topic:	Lecture 15 – Derivation of Energy Balance
Read:	Chapter 11, Sections 11.1, 11.2 and 11.3
Hand In:	Problem Set 13: P8-12_B Comprehensive Problem, Q11-1_A Do five i>clicker questions, Q11-7_A, Q11-13_A
In-Class Problem:	13 – Bring Laptops
Study Problems:	P8-17_B

17) Wednesday, November 4

Topic:	Lecture 16 – Chapter 11: Adiabatic Equilibrium Conversion and Reactor Staging
Read:	Finish Reading Chapter 11, Equilibrium conversion appendix
In-Class Problem:	14
Study Problems	P11-6_B

18) Monday, November 9

Topic:	Lecture 17 – Heat Exchange, Adiabatic Reactors ICPs
Read:	Chapter 12, Sections 12.1 through 12.2
Hand In:	Problem Set 14: P11-1_A (a), (b) and (d) only use Wolfram or Python, P11-3_B, P11-4_A, Q12-1_A, Q12-2_A Do five i>clicker questions
In-Class Problem:	15
Study Problem:	P12-6_A

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19) Wednesday, November 11

Topic:	Lecture 18 – Trends in Conversion and Temperature Profiles Applications of the Energy Balance to PFRs
Read:	Chapter 12, Section 12.3 and 12.4
Hand In:	Problem Set 15: P12-1 $_B$ (a), (b) and (c) LEP only use Wolfram or Python
In-Class Problem:	16 – Bring Laptops

20) Monday, November 16

Topic:	Lecture 19 – Multiple Reactions with Heat Effects *This topic is a major goal of this course, to carry out calculations for non-isothermal multiple reactions* Applications of the Energy Balance to PFRs
Hand In:	Problem Set 16: P12-4$_A$ (a) and (b), P12-14$_B$, P12-17$_B$, P12-21$_B$
In-Class Problem:	17 – Bring Laptops
Study Problem:	P12-20$_B$, i>clicker questions handed out in class

21) Wednesday, November 18

Topic:	Lecture 20 – CSTR and Review for Exam II
Study Problem:	P12-5$_C$

22) Monday, November 23

Topic:	Lecture 21 – EXAM II – Chapters 8, 11 and 12 Book and notecard are the only materials allowed
Hand In:	Problem Set 17: P12-26$_C$ Term Comprehensive Problem

23) Wednesday, November 25

Topic:	Lecture 22 – Multiple Steady States (MSS) Multiple Reactions with Heat Effects
Hand In:	Problem Set 18: P12-1$_B$ (e), (f) and (g) only use Wolfram or Python, Q13-1$_A$, Q13-2 $_A$ Do five i>clicker questions
Read:	Chapter 12, Sections 12.6 and 12.7
In-Class Problem:	18 – Bring a Ruler/Straight Edge
Study Problems:	P13-4$_B$

24) Monday, November 30

Topic:	Lecture 23 – Safety (CSI)
Read:	Chapter 13, Sections 13.1 through 13.3
Hand In:	Problem Set 19: P13-1$_B$ (b) and (f) only use Wolfram or Python, P13-9$_B$
In-Class Problem:	19 – Bring Laptops
Study Problems:	P13-2$_B$

25) Wednesday, December 2

Topic:	Lecture 24 –Catalysis Reactor Safety
Read:	Chapter 13, Section 13.5
Hand In:	Problem Set 20: Q10-1$_A$, Q10-2 $_A$ Do five i>clicker questions, P10-2$_A$ (ICG – only do the review – extra credit if you do the game), P10-4$_B$
In-Class Problem:	20
Study Problems:	P12-16$_B$, P13-11$_B$

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26) Monday, December 7

Topic:	Lecture 25 – Catalysis
Read:	Chapter 10, Sections 10.1 through 10.2.2
Hand In:	Problem Set 21: P10-3_A, P10-8_B, P10-10_B
In-Class Problem:	21
Study Problems:	P10-7_B, P10-9_B

27) Wednesday, December 9

Topic:	Lecture 23 – PSSH and Enzyme
Read	Chapter 9
Hand In:	Problem Set 22: Q9-1_A, Q9-2_A Do five i>clicker questions, P9-2_A (ICG), P9-5_B parts (b) and (c), P9-9_B, P9-14_B P9-20_A
In-Class Problem:	22
Study Problems:	P9-12_B, P9-17_B, P9-23_A

28) FINAL EXAM

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Synopsis for Chapter 1 – Mole Balances

Mole balances are the first building block of the chemical reaction engineering algorithm.
General: The goal of these problems are to reinforce the definitions and provide an understanding of the mole balances of the different types of reactors. It lays the foundation for step 1 of the algorithm in Chapter 5.

Key to Nomenclature

- • = Always assigned
- **AA** = Always assign one from the group of alternates
- **O** = Often assigned
- **I** = Infrequently assigned
- **S** = Seldom assigned
- **G** = Graduate level
- **N** = Never assigned

E.g., means problem • **P1-3$_B$** will be assigned every time I teach the course, problem **AA P1-8** means that this problem or one of the other problems with the prefix **AA** is always assigned for this chapter, Problem **I P1-2** will be infrequently assigned, Problem **O P1-6$_B$** will often be assigned, and Problem **S P3-16$_B$** is seldom assigned.

Alternates: In problems that have a dot in conjunction with **AA** means that one of the problems, either the problem with a dot or any one of the alternates are always assigned.

Time: Approximate time in minutes it would take a B student to solve the problem.

- **Q1-1$_A$** (9 seconds) Questions Before Reading (**QBR**).
  (a) John Falconer at the University of Colorado gives workshops on *Teaching* in which he points out that students have a better comprehension if they ask themselves a question before reading the text. The first question of each chapter, Q1, is just such a question.
  (b) The students are asked, at a minimum read through the *Questions* to help put the chapter and their studies in perspective.
  (c) I encourage using the i>Clicker questions.
- **Q1-2$_A$** (8-10 min) i>Clicker
- **Q1-5$_A$** (5-75 min) through **Q1-12$_A$**. To get a "feel" of the resources available, the students should spend a total of about 50-75 minutes on these questions.

Computer Simulations and Experiments (5-15 minutes per simulation)

These problems are interactive and are a minor paradigm shift in the way we use homework problems. Here the students are asked to explore the reaction and the reactor in which they occur to get an intuitive feel and understanding of the reactor system. This procedure is called **Inquiry Based Learning (IBL)**.

- **P1-1$_A$** (10-15 min) Good introduction to the use of Wolfram and Python.

Problems

- **I P1-2$_B$** (60 min) Problem reinforces wide range of applications of CRE and problem is given in the web module which can be accessed from the Web Home Page (*www.umich.edu/~elements*). Many students like this straight forward problem because they see how CRE principles can be applied to

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an everyday example. It is often assigned as an in-class problem where parts (a) through (f) are printed out from the web and given to the students in class. Part (g) is usually omitted.

- **P1-3$_B$** (45 min) I **always** assign this problem so that the students will learn how to use Polymath/MATLAB, Wolfram and Python before needing it for chemical reaction engineering problems. Most problems will use either Polymath or MATLAB to solve the end of chapter problems.
- **P1-4$_A$** (30 min) The Interactive Computer Games (ICGs) have been found to be a great motivation for this material. This ICG will help student AIChE chapters prepare for the Jeopardy Competition at the Annual AIChE Meeting.
- **P1-5$_A$** (10 min) Old Exam Question (OEQ) to reinforce the convention and stoichiometry in mole balances.

O **P1-6$_B$** (30 min) A hint of things to come on sizing reactors. Fairly straight forward problem to make a calculation. Uses Example 1-1 to calculate a CSTR volume. It is straight forward and gives the student an idea of things to come in terms of sizing reactors in chapter 4.

I **P1-7$_A$** (30 min) Helps develop critical thinking and analysis.

AA **P1-8$_A$** (20 min) **Puzzle problem** to identify errors in the solution. Many students especially those who enjoy working Sudoku or crossword puzzles enjoy working these types of problems.

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Solutions for Chapter 1 – Mole Balances

Useful Links:

1. Click on the link given below to download Wolfram/python codes for Ch-1
http://umich.edu/~elements/5e/01chap/obj.html#/

2. Click on the link given below to view Wolfram tutorial (for running Wolfram Codes)
http://umich.edu/~elements/5e/software/Wolfram_LEP_tutorial.pdf

3. Click on the link given below to view Polymath tutorial (for running Polymath Codes)
http://umich.edu/~elements/5e/tutorials/Polymath_LEP_tutorial.pdf

---

Q1-1 Individualized solution.

Q1-2 Individualized solution.

Q1-3

For CSTR:

$$V=\frac{F_{A0}X_A}{-r_{A,exit}}=\frac{F_{A0}X_A}{kC_A}=\frac{v_0C_{A0}X_A}{kC_{A0}(1-X_A)}=\frac{v_0X_A}{k(1-X_A)}=\frac{10^*\ 0.9}{0.23^*(0.1)}=391.3\ dm^3$$

Q1-4 Individualized solution.

Q1-5 Individualized solution

Q1-6 Individualized solution

Q1-7 (a)

The assumptions made in deriving the design equation of a batch reactor are:

- Closed system: no streams carrying mass enter or leave the system
- Well mixed, no spatial variation in system properties
- Constant Volume or constant pressure

Q1-7 (b)

The assumptions made in deriving the design equation of CSTR, are:

- Steady state
- No spatial variation in concentration, temperature, or reaction rate throughout the vessel

Q1-7 (c)

The assumptions made in deriving the design equation of PFR are:

- Steady state
- No radial variation in properties of the system

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Q1-7 (d)

The assumptions made in deriving the design equation of PBR are:

- Steady state
- No radial variation in properties of the system

Q1-7 (e)

For a reaction

$$A \rightarrow B$$

- $-r_A$ is the number of moles of A reacting (disappearing) per unit time per unit volume [=] moles/ (dm^3.s).
- $-r_A'$ is the rate of disappearance of species A per unit mass (or area) of catalyst [=] moles/ (time. mass of catalyst).
- r_A' is the rate of formation (generation) of species A per unit mass (or area) of catalyst [=] moles/ (time. mass catalyst).
- $-r_A$ is an ***intensive*** property, that is, it is a function of concentration, temperature, pressure, and the type of catalyst (if any), and is defined at any ***point*** (location) within the system. It is independent of amount. On the other hand, an extensive property is obtained by summing up the properties of individual subsystems within the ***total*** system; in this sense, $-r_A$ is independent of the 'extent' of the system.

Q1-8 Individualized solution.

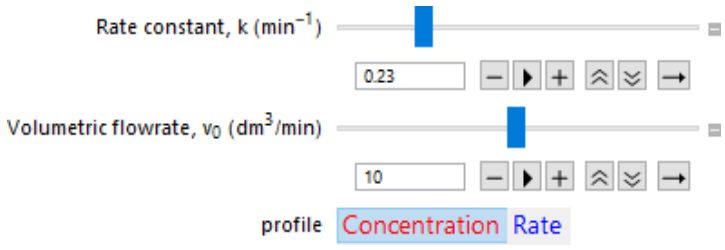
Q1-9 Individualized solution.

Q1-10 Individualized solution.

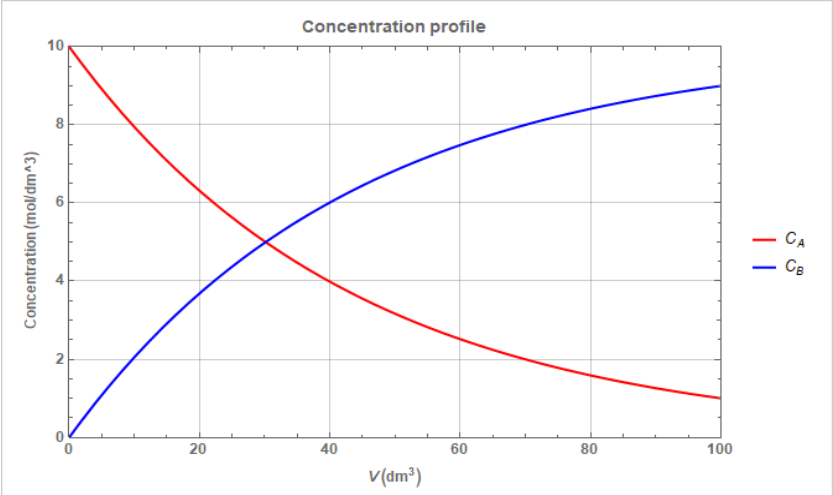
Q1-11 Individualized solution**.**

Q1-12 Individualized solution.

P1-1 (a) Example 1-3

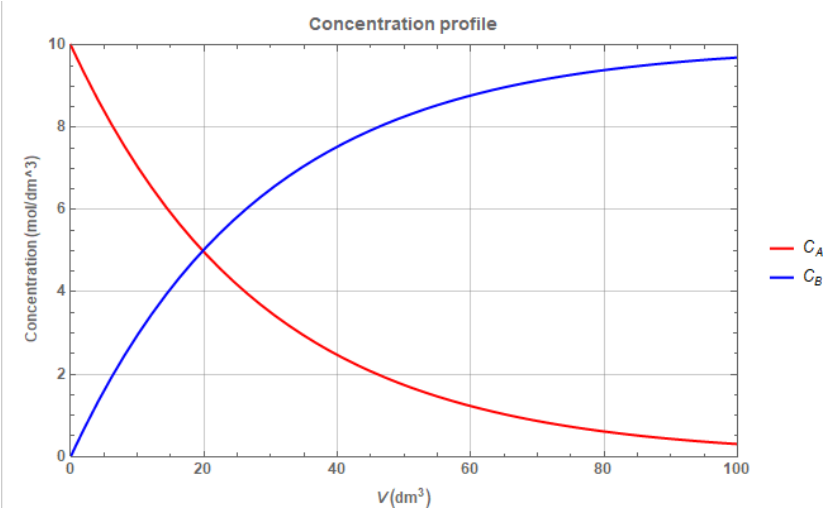


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The above graph represents intial Ca and Cb profiles for k=0.23 and v_0 = 10.

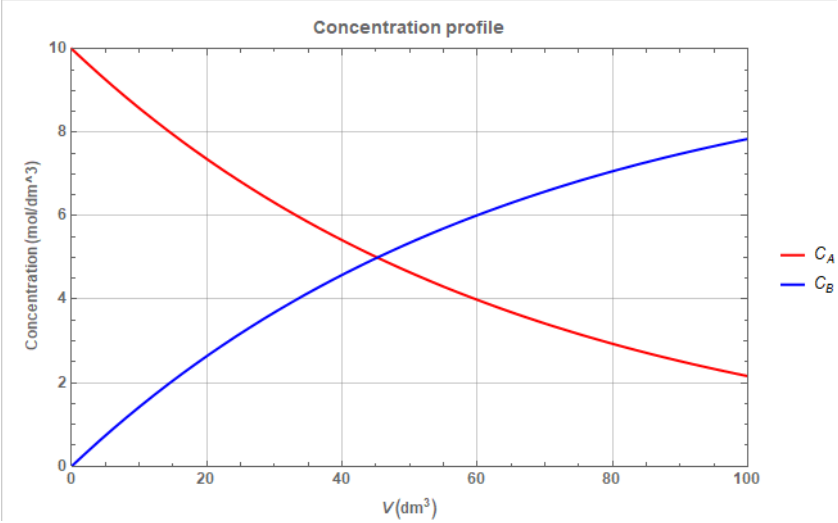
(i) With an increase in k (lets take k =0.35) for same volume and v_0 , Ca decreases and Cb increases



Now lets make k=0.23(initial value) and make an increase in v_0 (change from 10 to 15) for same volume.

We notice that now Ca increases and Cb decreases.

All of these graphs of concentration profiles are taken from Wolfram player by shifting the sliders.



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We can observe that varying rate constant has more effect on concentration profiles as compared to varying volumetric flow rate.

(ii) C_A decreases and C_B increases with an increase in k and K_e, and a decrease in v_0 for the same volume.

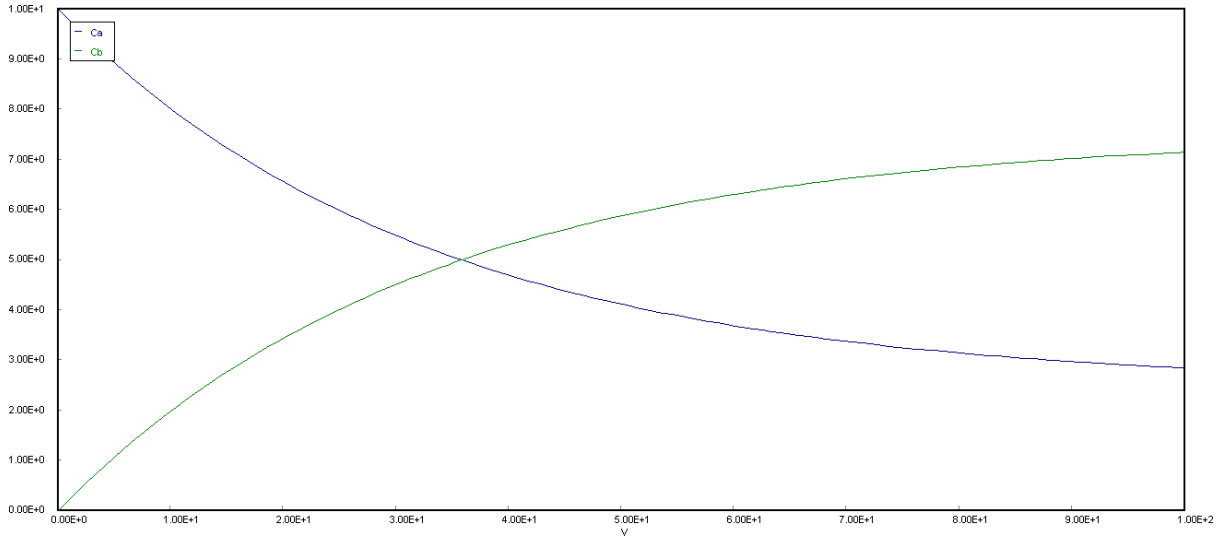
(iii) Individualized solution

(iv) See the following polymath code:

Polymath Code:

```
d(Ca)/d(V) = ra / v0
d(Cb)/d(V) = rb / v0
k = 0.23
Ke=3
ra = -k * (Ca-Cb/Ke)
rb = -ra
v0 = 10
V(0)=0
V(f)=100
Ca(0)=10
Cb(0)=0
```

Output:



POLYMATH Report
Ordinary Differential Equations

Calculated values of DEQ variables

	Variable	Initial value	Minimal value	Maximal value	Final value
1	Ca	10.	2.849321	10.	2.849321
2	Cb	0	0	7.150679	7.150679
3	k	0.23	0.23	0.23	0.23
4	Ke	3.	3.	3.	3.
5	ra	-2.3	-2.3	-0.1071251	-0.1071251
6	rb	2.3	0.1071251	2.3	0.1071251
7	V	0	0	100.	100.
8	v0	10.	10.	10.	10.

Differential equations

1 d(Ca)/d(V) = ra / v0
2 d(Cb)/d(V) = rb / v0

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Explicit equations

1 k = 0.23
2 Ke = 3
3 ra = -k * (Ca-Cb/Ke)
4 rb = -ra
5 v0 = 10

P1-2

Given

$A = 2*10^{10}\ ft^2$ $T_{STP} = 491.69R$ $H = 2000\,ft$

$V = 4*10^{13}\ ft^3$ T = 534.7 ° R P_O = 1atm

$R = 0.7302 \frac{atm\,ft^3}{lbmol\,R}$ y_A = 0.02 $C_S = 2.04*10^{-10} \frac{lbmol}{ft^3}$ C = $4*10^5$ cars

F_S = CO in Santa Ana winds F_A = CO emission from autos $v_A = 3000 \frac{ft^3}{hr}$ per car at STP

P1-2 (a)

Total number of lb moles gas in the system:

$$N = \frac{P_0 V}{RT}$$

$$N = \frac{1atm \times (4 \times 10^{13}\ ft^3)}{0.73 \frac{atm.ft^3}{lbmol.R} \times 534.69R} = 1.025 \times 10^{11} \text{ lb mol}$$

P1-2 (b)

Molar flowrate of CO into L.A. Basin by cars.

$$F_A = y_A F_T = y_A \cdot v_A C_T \Big|_{\text{STP}}^{\bullet \text{ no. of cars}}$$

$$F_T = \frac{3000\,ft^3}{hrcar} \times \frac{1lbmol}{359\,ft^3} \times 400000\ cars$$ (See appendix B)

$F_A = 6.685 \times 10^4$ lb mol/hr

P1-2 (c)

Wind speed through corridor is U = 15mph

W = 20 miles

The volumetric flowrate in the corridor is

v_O = U.W.H = (15x5280)(20x5280)(2000) ft^3/hr = 1.673×10^{13} ft^3/hr

P1-2 (d)

Molar flowrate of CO into basin from Santa Ana wind.

$$F_S := v_0 \cdot C_S$$

= 1.673×10^{13} ft^3/hr $\times 2.04 \times 10^{-10}$ lbmol/ft^3

= 3.412×10^3 lbmol/hr

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P1-2 (e)

Rate of emission of CO by cars + Rate of CO in Wind - Rate of removal of CO = $\frac{dN_{CO}}{dt}$

$$F_A + F_S - v_o C_{co} = V\frac{dC_{co}}{dt} \qquad \text{(V=constant, } N_{co} = C_{co}V\text{)}$$

P1-2 (f)

t = 0 , $C_{co} = C_{coO}$

$$\int_0^t dt = V\int_{C_{coO}}^{C_{co}} \frac{dC_{co}}{F_A + F_S - v_o C_{co}}$$

$$t = \frac{V}{v_o}\ln\left(\frac{F_A + F_S - v_o C_{coO}}{F_A + F_S - v_o C_{co}}\right)$$

P1-2 (g)

Time for concentration to reach 8 ppm.

$$C_{CO0} = 2.04\times10^{-8}\frac{lbmol}{ft^3},\ C_{CO} = \frac{2.04}{4}\times10^{-8}\frac{lbmol}{ft^3}$$

From (f),

$$t = \frac{V}{v_o}\ln\left(\frac{F_A + F_S - v_O \cdot C_{CO0}}{F_A + F_S - v_O \cdot C_{CO}}\right)$$

$$= \frac{4\,ft^3}{1.673\times10^{13}\frac{ft^3}{hr}}\ln\left(\frac{6.7\times10^4\frac{lbmol}{hr} + 3.4\times10^3\frac{lbmol}{hr} - 1.673\times10^{13}\frac{ft^3}{hr}\times2.04\times10^{-8}\frac{lbmol}{ft^3}}{6.7\times10^4\frac{lbmol}{hr} + 3.4\times10^3\frac{lbmol}{hr} - 1.673\times10^{13}\frac{ft^3}{hr}\times0.51\times10^{-8}\frac{lbmol}{ft^3}}\right)$$

t = 6.92 hr

P1-2 (h)

(1)

t_o	= 0	t_f	= 72 hrs
C_{co}	= 2.00E-10 lbmol/ft^3	a	= 3.50E+04 lbmol/hr
v_o	= 1.67E+12 ft^3 /hr	b	= 3.00E+04 lbmol/hr
F_s	= 341.23 lbmol/hr	V	= 4.0E+13 ft^3

$$a + b\sin\left(\frac{\pi t}{6}\right) + F_s - v_o C_{co} = V\frac{dC_{co}}{dt}$$

Now solving this equation using POLYMATH we get plot between C_{co} vs. t

See the following polymath code:

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Polymath Code:

```
v0 = 1.67*10^12
A= 35000
B = 30000
F = 341.23
V = 4*10^13
d(C)/d(t) = (A+B*sin(3.14*t/6)+F-v0*C)/V
C(0)=2.0e-10
t(0)=0
t(f)=72
```

Output:

POLYMATH Report

Ordinary Differential Equations

Calculated values of DEQ variables

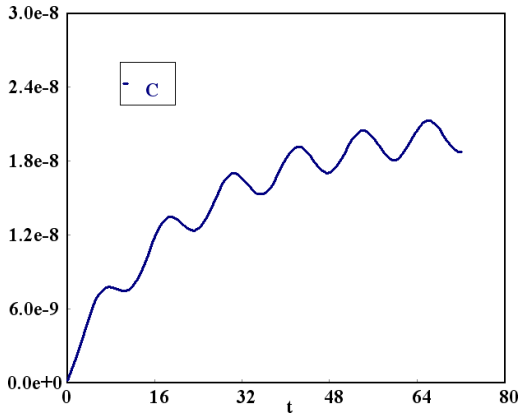
	Variable	Initial value	Minimal value	Maximal value	Final value
1	A	3.5E+04	3.5E+04	3.5E+04	3.5E+04
2	B	3.0E+04	3.0E+04	3.0E+04	3.0E+04
3	C	2.0E-10	2.0E-10	2.134E-08	1.877E-08
4	F	341.23	341.23	341.23	341.23
5	t	0	0	72.	72.
6	V	4.0E+13	4.0E+13	4.0E+13	4.0E+13
7	v0	1.67E+12	1.67E+12	1.67E+12	1.67E+12

Differential equations

1 d(C)/d(t) = (A+B*sin(3.14*t/6)+F-v0*C)/V

Explicit equations

1 v0 = 1.67*10^12
2 A = 35000
3 B = 30000
4 F = 341.23
5 V = 4*10^13



(2) $t_f = 48$ hrs $F_s = 0$

$$a + \; ! \; \underline{t} \therefore \quad b\sin\#\pi \; \& \; 6\% \; - \; v_o C_{co} = V \frac{dC_{co}}{dt}$$

Now solving this equation using POLYMATH we get plot between C_{co} vs t

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Polymath Code:

```
v0 = 1.67*10^12
A= 35000
B = 30000
F = 341.23
V = 4*10^13
d(C)/d(t) = (A+B*sin(3.14*t/6)+F-v0*C)/V
C(0)=2.0e-10
t(0)=0
t(f)=48
```

Output:

POLYMATH Report
Ordinary Differential Equations

Calculated values of DEQ variables

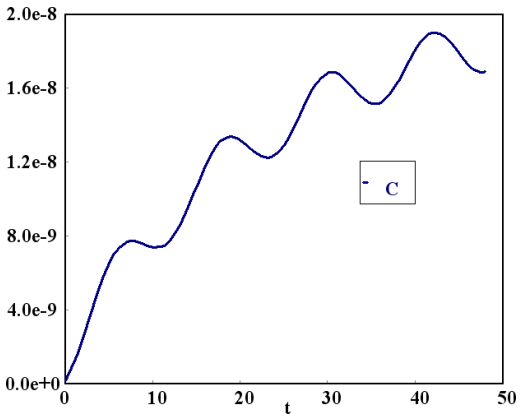
	Variable	Initial value	Minimal value	Maximal value	Final value
1	A	3.5E+04	3.5E+04	3.5E+04	3.5E+04
2	B	3.0E+04	3.0E+04	3.0E+04	3.0E+04
3	C	2.0E-10	2.0E-10	1.921E-08	1.71E-08
4	F	341.23	341.23	341.23	341.23
5	t	0	0	48.	48.
6	V	4.0E+13	4.0E+13	4.0E+13	4.0E+13
7	v0	1.67E+12	1.67E+12	1.67E+12	1.67E+12

Differential equations

1 d(C)/d(t) = (A+B*sin(3.14*t/6)+F-v0*C)/V

Explicit equations

1 v0 = 1.67*10^12
2 A = 35000
3 B = 30000
4 F = 341.23
5 V = 4*10^13



P1-2 (i)

Changing a -+ Increasing 'a' reduces the amplitude of ripples in graph. It reduces the effect of the sine function by adding to the baseline.

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Changing b -+ The amplitude of ripples is directly proportional to 'b'. As b decreases amplitude decreases and graph becomes smooth.

Changing v_0 -+ As the value of v_0 is increased the graph changes to a "shifted sin-curve". And as v_0 is decreased graph changes to a smooth increasing curve.

P1-3 (a)

Initial number of rabbits, x(0) = 500
Initial number of foxes, y(0) = 200
Number of days = 500

$$\frac{dx}{dt} = k_1 x - k_2 xy \quad \text{..... (1)}$$

$$\frac{dy}{dt} = k_3 xy - k_4 y \quad \text{..... (2)}$$

Given,

$$k_1 = 0.02 day^{-1}$$

$$k_2 = 0.00004 / (day \times foxes)$$

$$k_3 = 0.0004 / (day \times rabbits)$$

$$k_4 = 0.04 day^{-1}$$

See the following polymath code:

Polymath Code:

```
d(x)/d(t) = (k1*x)-(k2*x*y)
d(y)/d(t) = (k3*x*y)-(k4*y)
k1 = 0.02
k2 = 0.00004
k3 = 0.0004
k4 = 0.04
t(0)=0
t(f)=500
x(0)=500
y(0)=200
```

Output:

POLYMATH Report
Ordinary Differential Equations

Calculated values of DEQ variables

	Variable	Initial value	Minimal value	Maximal value	Final value
1	k1	0.02	0.02	0.02	0.02
2	k2	4.0E-05	4.0E-05	4.0E-05	4.0E-05
3	k3	0.0004	0.0004	0.0004	0.0004
4	k4	0.04	0.04	0.04	0.04
5	t	0	0	500.	500.
6	x	500.	2.962693	519.4002	4.219969
7	y	200.	1.128572	4099.517	117.6293

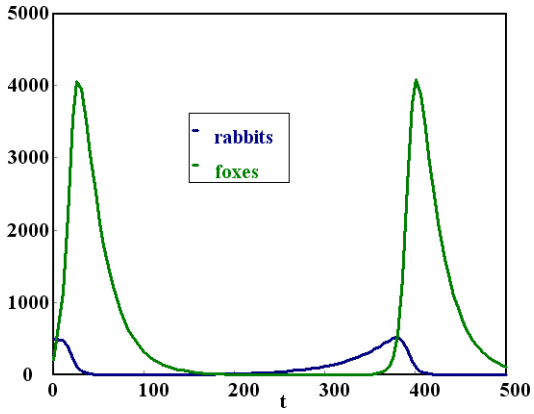
Differential equations

1 d(x)/d(t) = (k1*x)-(k2*x*y)
2 d(y)/d(t) = (k3*x*y)-(k4*y)

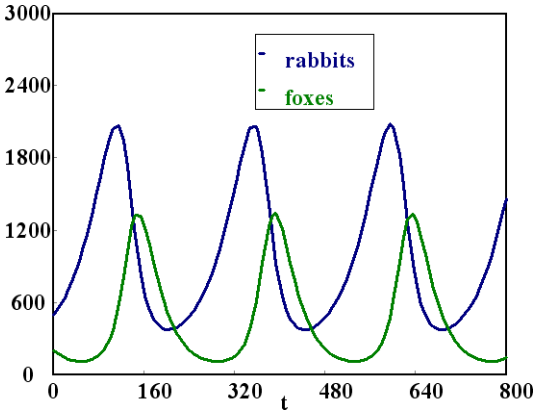
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Explicit equations

1 k1 = 0.02
2 k2 = 0.00004
3 k3 = 0.0004
4 k4 = 0.04



When, t_{final} = 800 and $k_3 = 0.00004\,/(day\,\xi\,rabbits)$



POLYMATH Report
Ordinary Differential Equations

Calculated values of DEQ variables

	Variable	Initial value	Minimal value	Maximal value	Final value
1	k1	0.02	0.02	0.02	0.02
2	k2	4.0E-05	4.0E-05	4.0E-05	4.0E-05
3	k3	4.0E-05	4.0E-05	4.0E-05	4.0E-05
4	k4	0.04	0.04	0.04	0.04
5	t	0	0	800.	800.
6	x	500.	377.9769	2086.088	1467.831
7	y	200.	114.6959	1341.876	143.6569

Differential equations

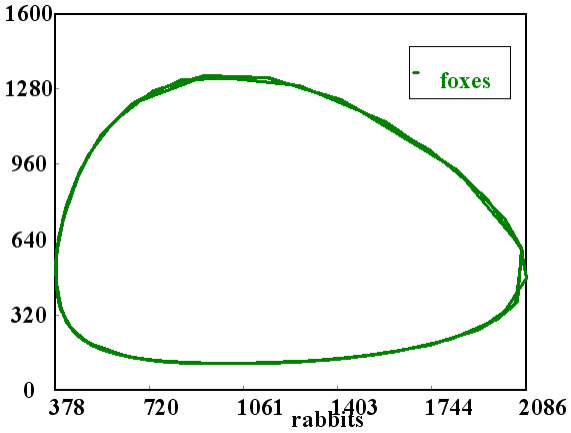
1 d(x)/d(t) = (k1*x)-(k2*x*y)
2 d(y)/d(t) = (k3*x*y)-(k4*y)

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Explicit equations

1 k1 = 0.02
2 k2 = 0.00004
3 k3 = 0.00004
4 k4 = 0.04

Plotting rabbits vs. foxes

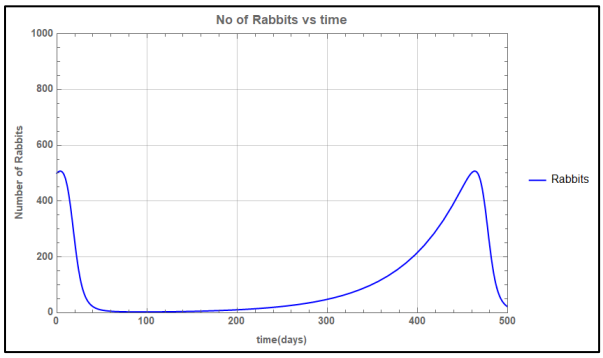


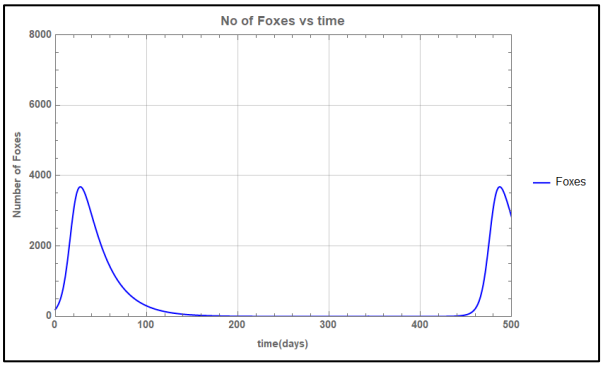
P1-3 (b)

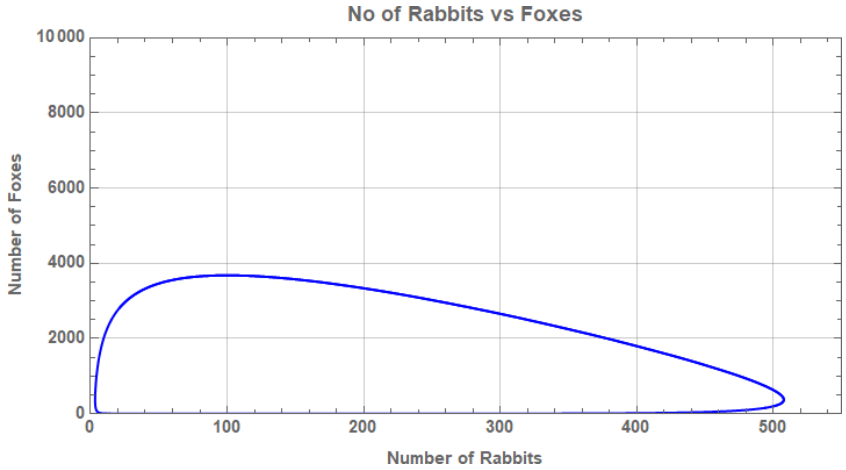
By increasing k_4 and decreasing k_2, foxes verses rabbits plot tends to become circular

P1-3 (c)

Below are the graphs when death rate is taken in to account







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P1-3 (d)

To solve the system of equation, we can use Polymath Nonlinear Equation Solver

Polymath Code:

```
f(x) = (x^3)*y-4*y^2+3*x-1
x(0) = 2
f(y) = 6*y^2-9*x*y-5
y(0) = 2
```

Polymath Output:

Calculated values of NLE variables

	Variable	Value	f(x)	Initial Guess
1	x	2.385039	2.53E-11	2.
	y	3.797028	1.72E-12	2.

Nonlinear equations

1 f(x) = (x^3)*y-4*y^2+3*x-1 = 0

2 f(y) = 6*y^2-9*x*y-5 = 0

P1-4 Individualized solution

P1-5

The correct answer is b.)

a.) Has the wrong sign for $-\int^V r_A dV$ and $-2\int^V r_A dV$. Should be $+\int^V r_A dV$ and $+2\int^V r_A dV$

b.) All are correct

c.) Wrong sign for F_c, should be $-F_c$.

d.) Wrong sign for $-\int^V r_C dV$, should be $+\int^V r_C dV$

P1-6 (a)

$-r_A = k$ with $k = 0.05$ mol/h dm^3

CSTR: The general equation is

$$V = \frac{F_{A0} - F_A}{-r_A}$$

Here $C_A = 0.01C_{A0}$, $v_0 = 10$ dm^3/min, $F_A = 5.0$ mol/hr

Also, we know that $F_A = C_A v_0$ and $F_{A0} = C_{A0} v_0$, $C_{A0} = F_{A0}/ v_0 = 0.5$ mol/dm^3

Substituting the values in the above equation we get,

$$V = \frac{C_{A0}v_0 - C_A v_0}{k} = \frac{(0.5)10 - 0.01(0.5)10}{0.05}$$

➔ V = 99 dm^3

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PFR: The general equation is

$$\frac{dF_A}{dV} = r_A = k \text{ , Now } F_A = C_A v_0 \text{ and } F_{A0} = C_{A0} v_0 \Rightarrow \frac{dC_A v_0}{dV} = -k$$

Integrating the above equation, we get

$$\frac{v_0}{k}\int_{C_{A0}}^{C_A} dC_A = \int_0^V dV \Rightarrow V = \frac{v_0}{k}(C_{A0} - C_A)$$

Hence **V = 99 dm^3**

Volume of PFR is same as the volume for a CSTR since the rate is constant and independent of concentration.

P1-6 (b)

$-r_A = kC_A$ with k = 0.0001 s^{-1}

CSTR:

We have already derived that

$$V = \frac{C_{A0}v_0 - C_A v_0}{-r_A} = \frac{v_0 C_{A0}(1-0.01)}{kC_A}$$

k = 0.0001s^{-1} = 0.0001 x 3600 hr^{-1}= 0.36 hr^{-1}

$$\rightarrow V = \frac{(10 dm^3/hr)(0.5 mol/dm^3)(0.99)}{(0.36 hr^{-1})(0.01*0.5 mol/dm^3)} \Rightarrow \textbf{V = 2750 dm}^3$$

PFR:

From above we already know that for a PFR

$$\frac{dC_A v_0}{dV} = r_A = -kC_A$$

Integrating

$$\frac{v_0}{k}\int_{C_{A0}}^{C_A} \frac{dC_A}{C_A} = -\int_0^V dV$$

$$\frac{v_0}{k}\ln\frac{C_{A0}}{C_A} = V$$

Again k = 0.0001s^{-1} = 0.0001 x 3600 hr^{-1}= 0.36 hr^{-1}

Substituting the values in above equation we get **V = 127.9 dm^3**

P1-6 (c)

$-r_A = kC_A^2$ with k = 300 dm^3/mol.hr

CSTR:

$$V = \frac{C_{A0}v_0 - C_A v_0}{-r_A} = \frac{v_0 C_{A0}(1-0.01)}{kC_A^2}$$

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Substituting all the values we get

$$V = \frac{(10 dm^3/hr)(0.5 mol/dm^3)(0.99)}{(300 dm^3/mol.hr)(0.01*0.5 mol/dm^3)^2} \Rightarrow \mathbf{V = 660\ dm^3}$$

PFR:

$$\frac{dC_A v_0}{dV} = r_A = -kC_A^2$$

Integrating

$$\frac{v_0}{k}\int_{C_{A0}}^{C_A} \frac{dC_A}{C_A^2} = -\int_0^V dV \Rightarrow \frac{v_0}{k}\left(\frac{1}{C_A} - \frac{1}{C_{A0}}\right) = V$$

$$\Rightarrow V = \frac{10 dm^3/hr}{300 dm^3/mol.hr}\left(\frac{1}{0.01 C_{A0}} - \frac{1}{C_{A0}}\right) = \mathbf{6.6\ dm^3}$$

P1-6 (d)

$C_A = 0.001 C_{A0}$

$$t = \int_{N_A}^{N_{A0}} \frac{dN}{-r_A V}$$

Constant Volume $V=V_0$

$$t = \int_{C_A}^{C_{A0}} \frac{dC_A}{-r_A}$$

Zero order:

$$t = \frac{1}{k}(C_{A0} - 0.001 C_{A0}) \quad \lambda = \frac{.999 C_{Ao}}{0.05} = 9.99h$$

First order:

$$t = \frac{1}{k}\ln\left(\frac{C_{A0}}{C_A}\right) = \frac{1}{0.0001}\ln\left(\frac{1}{.001}\right) = 69078 s = 19.19h$$

Second order:

$$t = \frac{1}{k}\left(\frac{1}{C_A} - \frac{1}{C_{A0}}\right) = \frac{1}{300}\left(\frac{1}{0.5 \cdot 0.001} - \frac{1}{0.5}\right) = 6.66h$$

P1-7 Enrico Fermi Problem

P1-7 (a) Population of Chicago = 4,000,000

Size of Households = 4

Number of Households = 1,000,000

Fraction of Households that own a piano = 1/5

Number of Pianos = 200,000

Number of Tunes/year per Piano = 1

Number of Tunes Needed Per Year = 200,000

Tunes per day = 2

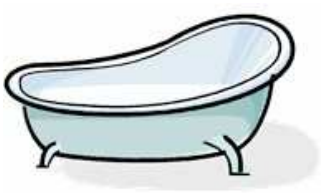
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$$\text{Tunes per year per tuner} = \frac{250\ days}{yr} \times \frac{2}{day} = 500/yr/tuner$$

$$\frac{200{,}000\ tunes}{yr} \times \frac{1}{500\ tunes/yr/tuner} = 400\ \text{Tuners}$$

P1-7(b) Assume that each student eats 2 slices of pizza per week.
Also, assume that it is a 14" pizza, with 8 pieces.
Hence, the area of 1 slice of pizza = 19.242 inch^2 = 0.012414 m^2
Thus, a population of 20000, over a span of 4 months, eats
20000 * 2 slices * 4 months * 4 weeks/month = 640000 slices of pizza, with a total area of
640000 * 0.012414 m^2 = 7945 m^2 of pizza in the fall semester.

P1-7(c) Assume you drink 1L/day
Assume you live 75 years*365days/year = 27375 days
1L/day*27375 days = 27375 L drank in life
Bathtub dimensions: 1m*0.7m*0.5m = 0.35m^3 = 350L/tub
Bathtubs drunk = 27375L*1tub/350L = 78 tubs



P1-7(d) Jean Valjean, Les Misérables.

P1-8
Mole Balance:

$$V = \frac{F_{A0} - F_A}{-r_A}$$

Rate Law :

$$-r_A = kC_A^2$$

Combine:

$$V = \frac{F_{A0} - F_A}{kC_A^2}$$

$$F_{A0} = v_0 C_A = 3\frac{dm^3}{s} \cdot \frac{2molA}{dm^3} = \frac{6molA}{s}$$

$$F_A = v_0 C_A = 3\frac{dm^3}{s} \cdot \frac{0.1\ molA}{dm^3} = \frac{0.3molA}{s}$$

$$V = \frac{(6-0.3)\frac{mol}{s}}{(0.03\frac{dm^3}{mol.s})(0.1\frac{mol}{dm^3})^2} = 19000\ dm^3$$

The incorrect part is in step 6, where the initial concentration has been used instead of the exit concentration.

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