

**PRAIRIE VIEW A&M UNIVERSITY
ROY G. PERRY COLLEGE OF ENGINEERING
DEPARTMENT OF CHEMICAL ENGINEERING
CHEG 3306-P02 KINETICS AND REACTOR DESIGN, SPRING 2022**

I. COURSE SYLLABUS IN ABET FORMAT

II. DESIGN PROJECT PRESENTATION

Summary of Topics covered by DESIGN PROJECT PRESENTATION
Original Design Project Questions & Master Solution/grading scheme used
Above Average (Graded original work)
Average (Graded original work)
Below Average (Graded original work)

III. EXAM II

Summary of Topics covered by EXAM II
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Above Average (Graded original work)
Average (Graded original work)
Below Average (Graded original work)

IV. REACTOR QUIZ

Summary of Topics covered by Quiz
Original Quiz Questions & Master Solution/grading scheme used
Above Average (Graded original work)
Average (Graded original work)
Below Average (Graded original work)

Course Description in ABET Format

CHEMICAL ENGINEERING DEPARTMENT CHEG 3306-P02: Kinetics and Reactor Design

1.	Course number and name:	CHEG 3306-P02:Kinetics and Reactor Design
2.	Credits and contact hours:	3 credit hours; 3 contact hours; Engineering Topic
3.	Instructor's or course coordinator's name:	Dr. Sheena M. Reeves
4.	Text book: Title:	Elements of Chemical Reaction Engineering
	Author:	H. Scott Fogler
	Publisher, Year & Edition:	Prentice-Hall, 5th Edition
	a. Other Supplemental material	
5.	Specific course information	
	a. Brief description of the content of the course (catalog description)	Application of fundamental concepts of reaction stoichiometry, kinetics, and equilibria to the interpretation of reaction rate data. Application of reaction rate, heat, and mass transfer correlations to the design of batch, continuous tank, and tubular reactors.
	b. Prerequisites or Co-requisites	CHEG 2053, MATH 4013, and CHEG 3053
	c. *Indicate whether a required, elective, or selected elective (as per definition provided) course in the program	Required
6.	Specific goals for the course	Students will be able to :
	a. specific outcomes of instruction	a. Identify and formulate reaction/reactor problems using the principles of mathematics, engineering, and science. b. Solve complex reaction engineering problems using graphing and computing tools. c. Select appropriate reactor and operating conditions for safe and economic reactor operation. d. Conduct a Review of Literature and determine preliminary design considerations. e. Perform detailed design of complex chemical reactors.
	b. Explicitly indicate which of the student outcomes listed in Criterion 3 or any other outcomes are addressed by the course.	This course addresses: Outcome 1 Ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. Outcome 2 Ability to apply engineering design to produce solutions that meet

		specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
7	Brief list of topics to be covered	Introduction/Notation Review (3) Mole Balances (3) Conversion/Reactor Sizing (3) Elementary Rate Laws (3) Stoichiometry (3) Isothermal Reactor Design/Pressure Drop (4) Multiple Reactions/Selectivity/Yield (4) Non-elementary Rates/Reaction Mechanisms (3) Semi-batch/Membrane Reactors (4) Thermodynamics/Heat Transfer (3) Catalysis (4) Design (3)

**CHEG 3306-02: KINETICS AND REACTOR DESIGN
SPRING 2022 SEMESTER**

Title of Assignment: DESIGN PROJECT PRESENTATION

TOPICS COVERED IN DESIGN PROJECT PRESENTATION

DESIGN PROJECT covered the following topics:

1. Mole balance
2. Rate law
3. Stoichiometry
4. Energy balance
5. Catalysis
6. Power requirements
7. PowerPoint presentations
8. Reactor simulation (ASPEN, Polymath)

CHEMICAL ENGINEERING DEPARTMENT
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
KINETICS AND REACTOR DESIGN
SPRING 2021 SEMESTER

Instructor: Dr. Sheena M. Reeves

Title of Assignment

Design Project

Outcome Measured Using this Assignment

Outcome 2

An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factor

Check the engineering design characteristics related to this assignment

X	Involves identifying the specific needs to be met by defining/understanding the problem and developing plans for the project to satisfy the need
X	Involves conducting a review of the literature and performing preliminary design by generating alternative ideas/solutions and applying creativity
X	Involves performing detailed engineering design leading to specification and fabrication/selection of components for system being designed.
X	Involves consideration of one or more of the following (Please check those involved in this assignment.)
X	Public health
X	Safety and welfare
X	Global factors
	Cultural factors
X	Social factors
X	Environmental factors
X	Economic factors
	Involves fabrication and testing of model or prototype

Brief justification of why this assignment is suitable for this outcome

This design project involves the design of a reactor given a set of design constraints. The project involved conducting a literature review, writing a report, and giving a presentation.

CHEG 3306-P02: Kinetics and Reactor Design

Group Project Spring 2022

(ABET Criteria 2. Ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.)

Background Report

Acrylic acid is produced from propylene, a gaseous product of oil refineries, by a two-step gas-phase oxidation via acrolein. For the background report, you will complete the Cover Sheet, Introduction, Project Summary/Details, and Materials Background section of your final report. This report is due on eCourses by **midnight on Saturday, April 9, 2022**. You will receive a Plagiarism report that must be addressed prior to submitting your final report.

***NOTE: ALL GROUP MEMBERS MUST BE COPIED ON ANY PROJECT EMAILS TO THE INSTRUCTOR.**

Project Overview

Acrylic acid has many usages in the chemical industry as an intermediate for several materials including polymers and textiles. The most commonly accepted method of producing acrylic acid is through the oxidation of propylene. For this project, the process will take in two series reactors containing different catalyst materials. All separation processes are ignored.

Project Details and Guidelines

Your group must design a reactor system to produce acrylic acid (AA) from the oxidation of propylene using SI units. The plant capacity is recorded as 10,000 metric tons of acrylic acid per day. Propylene vapor is available at 600kPa and 30°C. Assume that compressed air supplies oxygen to reactor and that the compressor has a turbine efficiency of 75% and a motor efficiency of 90%.

In the first reactor, propylene is converted to acrolein.

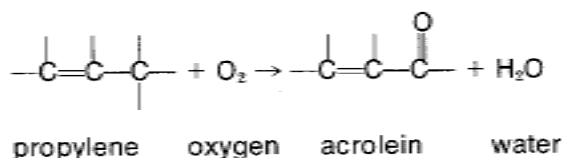


Figure 1: Propylene Oxidation Reaction (AIChE)

In the second reactor, the acrolein is converted to acrylic acid.

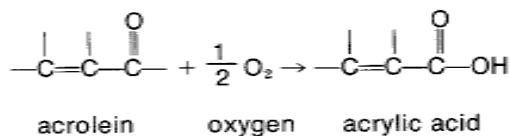


Figure 2: Reaction of Acrolein to Acrylic Acid (AIChE)

It is noted that side reactions may occur which produce acetic acid and water.

The propylene reactions are:		ΔH_{Rx} kcal/kgmole C ₃ H ₆ at 20 deg C
(1) C ₃ H ₆ + 1.5 O ₂ → C ₃ H ₄ O ₂ + H ₂ O		1.61 E5
(2) C ₃ H ₆ + 2.5 O ₂ → C ₂ H ₄ O ₂ + CO ₂ + H ₂ O		2.76 E5
(3) C ₃ H ₆ + 4.5 O ₂ → 3CO ₂ + 3H ₂ O		4.89 E5

Figure 3: Main and By-Products of Propylene Oxidation (AIChE)

As a safety precaution, steam at 550kPa is fed into the reactor at a composition of 40 mole% and an O₂/C₃H₆ feed

ratio of 2.5 must be maintained. ***Your group must research catalysts for this process and email a memo of your catalyst to Dr. Reeves by Monday, March 28, 2022. NOTE: CORRECT MEMO/EMAIL FORMAT IS REQUIRED.*** Each group will have different catalysts so choose wisely and quickly. Before a catalyst is accepted, each group must email a memo with the catalyst of choice, the diameter of the catalyst, the density of the catalyst, and source of information (pdf of journal article). A good reference will contain values such as reaction rate constants, equilibrium constants, activation energy, etc.

For this project, you will:

1. *Complete the steps of the algorithm including energy balance and pressure drop equations assuming elementary reactions.*
2. *Input all information into Polymath and produce graphs for temperature, conversion, and concentration based on reactor type. (REACTOR #1 only).*
3. *Determine the operating conditions of each reactor and the size of the reactor required.*
4. *Determine the material balance and energy balance for each reactor in ASPEN HYSYS (simulation).*
5. *Achieve a yield of greater than 75% acrylic acid.*
6. *Determine the bulk volume of catalyst ($\rho_b = 4.75 \frac{\text{kg}}{\text{m}^3}$) and/or number of tubes required to meet specifications based on type of reactor.*
7. *Determine the heat duty, type of coolant, and amount of coolant (if necessary) for each reactor.*
8. *Assume the reactor tubes are 45 mm. ID, 50 mm OD, and 5 m long.*
9. *Perform an economic analysis of operating and capital costs (labor, utility, materials, and equipment) to determine the feasibility of your process.*
10. *If you find competing data in your literature review for your catalyst, discuss them with Dr. Reeves.*

ADDITIONAL INFORMATION:

Information gathered from a pilot plant. (Acquired from AIChE database)

Table 1. Physical Property Data

Component	Mole Wt.	Normal Boil. Point Deg C	Melt. Point Deg C	Heat of Comb. ¹ Kcal/g-mole	Heat of Vap. ² cal/g-mole	Liquid Sp. Gr. Typ. Cond.
C ₃ H ₆	42.08	-47.4	-185.4	489.4	4697	—
CO ₂	44.01	—	—	—	NR	—
AA	72.06	141.6	13.0	317.2	7872	1.010
HAc	60.05	117.9	16.6	218.4	5733	0.973
O ₂	32.00	—	—	—	NR	—
N ₂	28.01	—	—	—	NR	—
H ₂ O	18.02	100.0	0.0	—	Use Steam Tables	—
CH ₄	16.04	—	—	211.2	NR	—

¹At 20 deg C organic + O₂ to CO₂(g) + H₂O (l)

²At normal boiling point.

Table 2. Heat Capacity Data

$$CP = A + B \times T \times 10^{-3} + C \times T^2 \times 10^{-7}$$

Where CP is cal/g/deg C
and T is deg C

Component	Liquid			Vapor		
	A	B	C	A	B	C
C ₃ H ₆				0.339	1.007	-5.80
CO ₂				0.196	0.230	-1.59
AA	0.4833	0.418	34.67	0.428	5.106	-280.26
HAc	0.4790	0.524	11.28	0.703	-1.086	-8.34
O ₂				0.223	0.043	-0.06
N ₂				0.247	0.048	-0.08
H ₂ O	0.9985	0.057	16.52	0.445	0.026	7.74
CH ₄				0.512	0.816	0.55

FINAL REPORT GUIDELINES:

***ALL EQUATIONS MUST BE TYPED USING EQUATION EDITOR.**

- Overall, the report should be at least ten pages in length, double-spaced, 12 pt. Times New Romans font, and contain one inch margins. Preliminary report and presentation are due **May 2, 2022**. Project presentations are **May 3rd and 5th, 2022**. Each group should upload their finalized report as a PDF to eCourses by **May 11, 2022**.
- The report should not contain any instances of **plagiarism**. All thoughts/facts not belonging to group members must be cited within text (Last Name of Author/Editor, Year). Since this report is a technical paper, **no direct quotes are allowed**.

3. The report should be grammatically correct and contain new paragraphs when a new main topic is discussed. Do not use words such as **I, you, me, we, they, and us**.
4. Follow the outline of:
 - Cover Sheet
 - Report title, course name, group members, instructors, and the due date
 - **Project Summary**
 - ***This section is a 1-2 page summary of your design. It includes a 1-2 sentence description of the problem statement and includes all design parameters for the project.***
 - ***It is considered a summary of the overall process and it provides direct answers to the given design questions.***
 - Introduction/Material Background (3-5 sources of information required; not websites)
 - This section should contain the background information on acrylic acid and the propylene oxidation process.
 - Questions to answer include: Why the process is important? How does acrylic acid impact the chemical industry? Production vs. Usage? Projections? What are the Process Safety considerations?
 - Problem Statement/Project Details
 - This section details the given design problem and any constraints given; ***do not copy and paste the assignment as given***. Summarize and write it in your own words.
 - It should discuss the limitations and questions that are posed in this document.
 - This section discusses the reaction mechanism and other parameters given in this document. NOTE: You must discuss the information and not simply place it in a table.
 - Design Specifications
 - This section details your catalyst selection and expected results (yield, selectivity, conversion, etc.) based on your literature search.
 - It shows the reaction and products that are expected as a result of your catalyst selection.
 - This section contains your kinetic and/or transport models (algorithm): Mole balance, rate law, stoichiometry, combine, pressure drop, energy balance, evaluate (Polymath), simulate (ASPEN HYSYS). You must discuss all graphs and tables.
 - Results and Discussion
 - Answers all questions such as final volume, composition, etc.
 - Provide printouts of stream specifications, reactor parameters, flow chart, etc.
 - Discuss and label all figures and tables. Do not insert random tables of data.
 - References
 - References should be from credible journal articles and library books.
 - You should cite information within the text (Last Name, Year) and provide a list of references at the end of the document.
 - Utilized the APA style.
 - Appendix
 - Appendix may contain summary reports and graphs, handwritten calculations, memos, and any other notable material that is not discussed in the body of the report.
5. Follow the framework of:
 - a. Tell the reader what you will discuss.
 - b. Discuss the material with the reader.
 - c. Tell the reader what was discussed.

ABOVE AVERAGE



DEPARTMENT OF CHEMICAL ENGINEERING
CHEG 3306-P02: KINETICS AND REACTOR DESIGN
COURSE ASSIGNMENT GRADING AND OUTCOME ASSESSMENT
SHEET FOR SPRING 2022 SEMESTER

ABET OUTCOME 2: Show an ability to design a system, a component, or a process to meet desired need within constraints.

Group Name: 1 Date: 05/10/2022
 Title of Assignment: Acrylic Acid Production

Competency Area	Points	Grade
Presentation, Design (Outcome 2.3)	85	70
Determine the type of reactor and the phase of the reactants/products.	5	5
Determine the operating temperature and pressure.	5	5
Determine reactor volume, number of tubes, and catalyst weight required	10	7
Presents an accurate algorithm of equations	5	4
Meet design constraints given in the problem statement.	10	7
Has simulation results from Polymath for material and energy balances	15	13
Has an ASPEN reactor simulation	15	10
Includes a cost analysis	5	4
Dressed for occasion, speak with confidence, answers questions professionally	5	5
Determine the heat required/produced during process	5	5
Research common safety procedures require for the reactor materials.	5	5
Report, Content (Outcome 2.2)	85	56
Contains the required sections:	5	5
At least ten pages, double-spaced, 12 pt Times New Roman font; Grammar	5	2
Contains all design findings in the Project Summary	10	3
Contains an adequate reaction mechanism explanation based on chosen catalyst	10	10
Introduces the topic of acrylic acid production	5	5
Explains/discusses tables and graphs in the report	10	8
Details a full design of the reactor operation including design equations and parameters	15	10
Cost Analysis is explained in report	10	0
Concludes by listing design challenge, approach to solving, and the solution achieved	5	3
Write a full technical report of literature review without plagiarism.	10	10
Group Participation Grade (input from group members; Outcome 2.3)	30	
Handwritten Algorithm	20	
Background Report (Outcome 2.1)	30	
Simulation	50	35
TOTAL POINTS	300	

NOTES:

- Presentation:
- What is the diameter of the catalyst?
 - Separate out information on graphs.
 - Reactor #1: What are unit for F_i ?
How much are you trying to produce?
 - Did not calculate # of tubes.
 - Used very little acrolein for reaction #2
 - Had cost analysis and good Polymath
 - ASPEN was incomplete.

Graphs are missing titles.

REACTOR DESIGN:
Catalytic Oxidation of Propylene to Acrylic Acid

DR. REEVES - CHEG 3063-P02

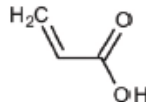
Group members:
Zenab Coulibaly-Diakite,
Ebonie Henderson, and Devin Luckett

Introduction

Acrylic Acid

- Versatile Product**
- Several industries
 - Nail Polish, Sundry Pads in Cosmetics
 - Weather resistant coatings in Construction
 - Two-step oxidation process from Propylene

- Hazards**
- Colorless Liquid
 - Strong pungent odor
 - Corrosive
 - Irritates skin, nose and lungs



Problem Statement

- Plant Capacity of 10,000 Metric Ton per Year (about 15854.9 moles per hour)
- Propylene Vapor 600 kPa and
- Minimum Yield of 75 % and 303 K
- Reactor Tube Dimensions
 - 45 mm Inner Diameter
 - 50 mm Outer Diameter
 - 5 m long

Reactors and Catalyst Selection

Reactor #1

- o Propylene to Acrolein
- o Packed Bed Reactor
- o Catalyst
- o Gamma Bismuth Molybdenum
 - o High Selectivity
 - o High Temperature
 - o 650.15 - 723.15 K

Reactor #2

- o Acrolein to Acrylic Acid
- o Packed Bed Reactor
 - o High conversion per catalyst weight
- o Alpha Cobalt Molybdenum Oxide
 - o Yellow powder
 - o Low selectivity
 - o Low temperature : 523 – 700 K

Reactor #1

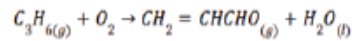
Propylene to Acrolein Parameters

Conversion (X) = 55%
Selectivity (S) = 88%

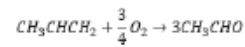
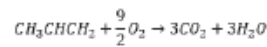
Gamma Bismuth Molybdenum

Pore Radius = 21.67 nm
Pore Volume = 4.5×10^{-3} /g
Density = 6950 g/m³

Reaction Chemistry



Side Reaction Chemistry



REACTOR #1 CONT'D

Mole Balance

$$\begin{aligned} d(Fa)/d(W) &= r_a \\ d(Fb)/d(W) &= r_b \\ d(Fc)/d(W) &= r_c \\ d(Fd)/d(W) &= r_d \\ d(Fe)/d(W) &= r_e \\ d(Ff)/d(W) &= r_f \end{aligned}$$

Rate Law

$$r_a = r_{1a} + r_{2a} + r_{3a} + r_{4a}$$

$$r_b = r_{1b} + r_{2b} + r_{3b} + r_{4b}$$

$$r_c = r_{1c}$$

$$r_d = r_{1d} + r_{2d} + r_{3d}$$

$$r_e = r_{2e}$$

$$r_f = r_{3f}$$

$$-r_{1a} = K_1 C_a C_b$$

$$-r_{2a} = K_2 C_a C_b^2$$

$$-r_{3a} = K_3 C_a C_b^{3/4}$$

Reactor #2

Acrolein to Acrylic Acid Parameters

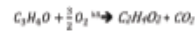
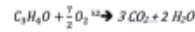
Conversion (X) = 45%
Selectivity (S) = 11.8%
Yield = 75%

Alpha Cobalt Molybdenum
Specific Surface = $9.0 \text{ m}^2 \cdot \text{g}^{-1}$
Weight = 5 g
Density = 8.4 g/cm^3

Main Reaction



Side Reactions



Acrolein : A , Oxygen : B , Acrylic acid : C , Carbone Dioxide : D , Water : E , Acetic Acid : F

REACTOR#2 CONT'D

Mole Balances

$$\frac{dF_A}{dW} = r_A$$

$$\frac{dF_B}{dW} = r_B$$

$$\frac{dF_C}{dW} = r_C$$

$$\frac{dF_D}{dW} = r_D$$

$$\frac{dF_E}{dW} = r_E$$

$$\frac{dF_F}{dW} = r_F$$

Rate laws

$$-r_A = k_1 C_A C_B^{1/2} + k_2 C_A C_B^{7/2} + k_3 C_A C_B^{3/2}$$

$$-r_B = \frac{1}{2} k_1 C_A C_B^{1/2} + \frac{7}{2} k_2 C_A C_B^{7/2} + \frac{3}{2} k_3 C_A C_B^{3/2}$$

$$-r_C = -k_1 C_A C_B^{1/2}$$

$$-r_D = -3 k_2 C_A C_B^{7/2} - k_3 C_A C_B^{3/2}$$

$$-r_E = -2 k_2 C_A C_B^{7/2}$$

$$-r_F = -k_3 C_A C_B^{3/2}$$

REACTOR#2 CONT'D

Stoichiometry

$$C_A = \frac{F_A}{v} = C_{T0} \frac{F_A}{F_T} \frac{P}{P_0} \frac{T_0}{T}$$

$$C_B = \frac{F_B}{v} = C_{T0} \frac{F_B}{F_T} \frac{P}{P_0} \frac{T_0}{T}$$

$$C_C = \frac{F_C}{v} = C_{T0} \frac{F_C}{F_T} \frac{P}{P_0} \frac{T_0}{T}$$

$$C_D = \frac{F_D}{v} = C_{T0} \frac{F_D}{F_T} \frac{P}{P_0} \frac{T_0}{T}$$

$$C_E = \frac{F_E}{v} = C_{T0} \frac{F_E}{F_T} \frac{P}{P_0} \frac{T_0}{T}$$

$$C_F = \frac{F_F}{v} = C_{T0} \frac{F_F}{F_T} \frac{P}{P_0} \frac{T_0}{T}$$

Pressure Drop

$$\frac{dP}{dW} = -\frac{\alpha}{2P} \left(\frac{F_T}{F_{T0}} \right) \left(\frac{T}{T_0} \right)$$

$$\alpha = \frac{2\beta_0}{a\rho_c(1-\phi)p_0}$$

$$\beta_0 = \frac{G(1-\phi)}{\rho_g g_c D_p \phi^3}$$

Energy Balance

$$\frac{dT}{dW} = \frac{Ua*(T_0-T) - r_{1a}\Delta H_{r1} + r_{2a}\Delta H_{r2} + r_{3a}\Delta H_{r3}}{F_aCp_a + F_bCp_b + F_cCp_c + F_dCp_d + F_eCp_e + F_fCp_f}$$

$$\Delta H_r = \Delta H_{f(Products)} - \Delta H_{f(reactants)}$$

POLYMATH and ASPEN

Polymath Report

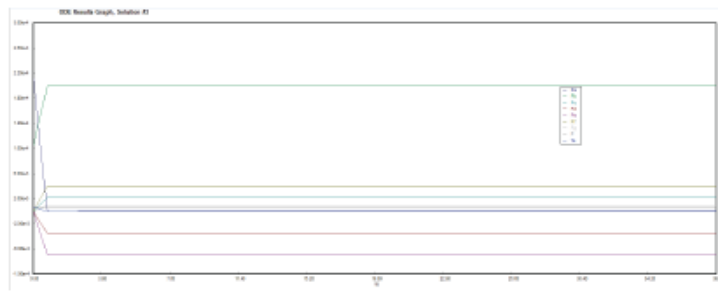
Reactor #1

	Variable	Initial value	Minimal value	Maximal value	Final value
1	W	0	0	38.	38.
2	Fa	2.114E+04	-6.599E-09	2.114E+04	1.511E-12
3	Fb	1.057E+04	1.057E+04	2.004E+04	2.004E+04
4	Fc	0	0	2284.61	2284.61
5	Fd	0	-3505.152	0	-3505.152
6	Fe	0	-6853.829	0	-6853.829
7	Ff	0	0	4058.759	4058.759
8	Fg	0	0	1064.067	1064.067
9	P	900.	900.	900.1023	900.1023
10	Ta	723.15	37.15387	723.15	50.98754
11	Faa	41.67	41.67	41.67	41.67
12	Fto	3.171E+04	2.004E+04	3.171E+04	2.004E+04
21	Oto	0.2412034	0.2412034	0.2412415	0.2412415
22	Ec	83.9	83.9	83.9	83.9
23	Ed	196.9	196.9	196.9	196.9
24	Ca	7.448239	-1.641E-12	7.448239	8.427E-16
25	Cb	3.724474	3.724474	11.17652	11.17652
38	ra	-9224.418	-9224.418	5.487E-08	-2.82E-11
39	rd	2.767E+04	-1.646E-07	2.767E+04	8.46E-11
40	rb	8.031E+05	-5.308E-07	8.031E+05	2.727E-10
41	re	-5.354E+05	-5.354E+05	3.539E-07	-1.816E-10
42	rg	2.767E+04	-1.646E-07	2.767E+04	8.46E-11
43	Cc	0	0	1.274034	1.274034
44	Cd	0	-1.954681	0	-1.954681

[illegible][illegible][illegible]

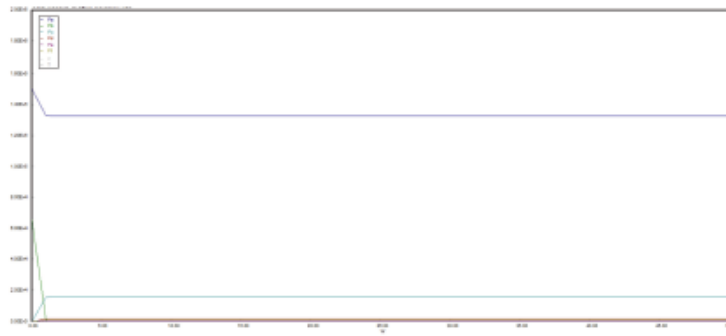
Polymath Graph

Reactor #1



Polymath Graph

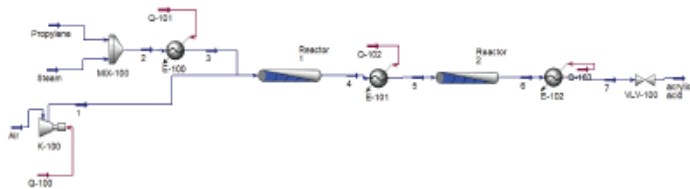
Reactor #2



Design of Production System Includes

- ❖ 2 Heat exchanger
- ❖ Mixer
- ❖ 2 Reactors in series
- ❖ Air Compressor
- ❖ 2 Valves

Aspen Hysy Design



Safety Specification

- ❖ Proper PPE
- ❖ Exposure of Chemicals
- ❖ Very flammable
- ❖ Corrosion Protection
- ❖ Release large amounts of heat
- ❖ Wash skin after handling



Name	acrylic acid
Pressure [kPa]	600
Temperature [C]	580.948
Mass Flow [kg/h]	583.786
Std Ideal Liq Vol Flow [m3/h]	0.974262
Vapor / Phase Fraction	1
Molar Enthalpy [kJ/kgmole]	23178.4
Utility Type	
Stream Price	
Stream Price Basis	Molar Flow
Cost Rate [Cost/s]	

Aspen Hysy Result

References

- [1] American Psychological Association. (2013). *Handbook of statistics: The psychology of statistics*. Washington, DC: American Psychological Association.
- [2] American Psychological Association. (2013). *Handbook of statistics: The psychology of statistics*. Washington, DC: American Psychological Association.
- [3] American Psychological Association. (2013). *Handbook of statistics: The psychology of statistics*. Washington, DC: American Psychological Association.
- [4] American Psychological Association. (2013). *Handbook of statistics: The psychology of statistics*. Washington, DC: American Psychological Association.
- [5] American Psychological Association. (2013). *Handbook of statistics: The psychology of statistics*. Washington, DC: American Psychological Association.
- [6] American Psychological Association. (2013). *Handbook of statistics: The psychology of statistics*. Washington, DC: American Psychological Association.
- [7] American Psychological Association. (2013). *Handbook of statistics: The psychology of statistics*. Washington, DC: American Psychological Association.
- [8] American Psychological Association. (2013). *Handbook of statistics: The psychology of statistics*. Washington, DC: American Psychological Association.
- [9] American Psychological Association. (2013). *Handbook of statistics: The psychology of statistics*. Washington, DC: American Psychological Association.
- [10] American Psychological Association. (2013). *Handbook of statistics: The psychology of statistics*. Washington, DC: American Psychological Association.



AVERAGE



DEPARTMENT OF CHEMICAL ENGINEERING
CHEG 3306-P02: KINETICS AND REACTOR DESIGN
COURSE ASSIGNMENT GRADING AND OUTCOME ASSESSMENT
SHEET FOR SPRING 2022 SEMESTER

ABET OUTCOME 2: Show an ability to design a system, a component, or a process to meet desired need within constraints.

Group Name: 5 Date: 05.10.2022
 Title of Assignment: Acrylic Acid Production

Competency Area	Points	Grade
Presentation, Design (Outcome 2.3)	85	61
Determine the type of reactor and the phase of the reactants products.	5	5
Determine the operating temperature and pressure.	5	5
Determine reactor volume, number of tubes, and catalyst weight required	10	7
Presents an accurate algorithm of equations	5	3
Meet design constraints given in the problem statement.	10	6
Has simulation results from Polymath for material and energy balances	15	10
Has an ASPEN reactor simulation	15	8
Includes a cost analysis	5	5
Dressed for occasion, speak with confidence, answers questions professionally	5	5
Determine the heat required/produced during process	5	2
Research common safety procedures require for the reactor materials.	5	5
Report, Content (Outcome 2.2)	85	64
Contains the required sections:	5	5
At least ten pages, double-spaced, 12 pt Times New Roman font; Grammar	5	5
Contains all design findings in the Project Summary	10	8
Contains an adequate reaction mechanism explanation based on chosen catalyst	10	8
Introduces the topic of acrylic acid production	5	5
Explains/discusses tables and graphs in the report	10	8
Details a full design of the reactor operation including design equations and parameters	15	12
Cost Analysis is explained in report	10	0
Concludes by listing design challenge, approach to solving, and the solution achieved	5	3
Write a full technical report of literature review without plagiarism.	10	10
Group Participation Grade (input from group members; Outcome 2.3)	30	
Handwritten Algorithm	20	
Background Report (Outcome 2.1)	30	
Simulation	50	35
TOTAL POINTS	300	

NOTES:

Presentation:

- Missing dT/dw
- Did not use r_A for rate laws

• Reactor #1 $D_p = 3.2 \text{ nm}$
 $\rho = 0.05 \text{ kg/m}^3$??

Reactor #2 $D_p = 0.004 \text{ m}$

- $\rho = \text{extremely small (pic range??)}$
- Correctly used $F_{E0} = F_E$
- "Catalyst ran out fast?"
- Assumed $A_c = 0$?
- Too many crossed lines on PFD
- Conversion scale?
- Good CAPCOST slide
- Incomplete simulation results.
- Needs a unity of units

CHEG 3306-P02
GROUP 5
TYECIA FRANKLIN
ARIEL KINSEY
CEDRIC SANHOUDI

Production of Acrylic Acid

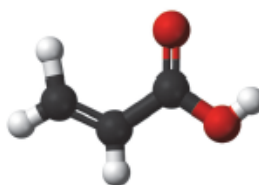
Outline

2

- Background
- Project Scope
- Reaction Mechanism
- Reactor Selection
- Catalyst Selection
- Design Specifications
- Safety Considerations
- Economic Analysis
- References

Background

- ▶ Acrylic Acid $C_3H_4O_2$
- ▶ Simplest unsaturated carboxylic acid
- ▶ Obtained by oxidation of Propylene
- ▶ Expected annual production of 8,750 kilo tons by 2022
- ▶ Commonly used in creation of polymers in many industries(plastic, medical, water treatments....)



Project Scope

4

Problem Statement

- Design a reactor by oxidizing propylene to acrylic acid
- Produce 10,000 MT/year of Acrylic Acid
- Implement a catalyst
- Input data into polymath

Project Goals

- Determine operating conditions and size of reactors
- Simulate in Aspen HYSYS
- Bulk catalyst volume/number of tubes calculation
- Perform economic analysis

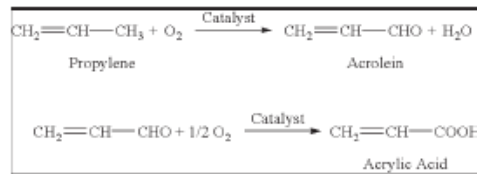
Reaction Mechanism

A= Propylene
B= Oxygen
C=Acrolein
D=Water
E=Acrylic Acid

5

Reaction 1 in Reactor 1:
From propylene to Acrolein

Reaction 2 in Reactor 2:
From Acrolein to Acrylic acid

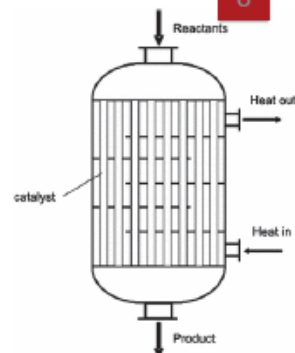


Reactor Selection

Packed Bed Reactors

- High conversion rate/ catalyst weight
- Low operating cost
- Continuous operation

6



Catalyst Selection

7

▶ Copper Polycyclidine with Silica Oxide Inert (CuPC-Py/SiO₂)

- ▶ For conversion of propylene into acrolein
- ▶ Conversion percentage of 29.5%
- ▶ Diameter: 3.2e-09m
- ▶ Density: 0.05 kg/m³

▶ Vanadium Molybdenum Oxide (VMO₃O₁₁)

- ▶ For conversion of acrolein into Acrylic acid
- ▶ Conversion percentage of 70%
- ▶ Diameter: 0.004m
- ▶ Density: 1.48e-12 kg/m³

Mole Balances and Rate Laws

8

- ▶ $\frac{dF_a}{dw} = ra'$
- ▶ $\frac{dF_b}{dw} = rb'$
- ▶ $\frac{dF_c}{dw} = rc'$
- ▶ $\frac{dF_d}{dw} = rd'$
- ▶ $\frac{dF_e}{dw} = re'$

$$r_a = -k_1 C_a C_b$$

$$r_b = -k_1 C_a C_b$$

$$r_c = k_1 C_a C_b$$

$$r_d = k_1 C_a C_b$$

$$r_{2e, net} = k_1 C_a C_b - k_2 C_e C_b^{1/2}$$

$$r_{2B, net} = \frac{1}{2} (-k_1 C_a C_b + k_2 C_e C_b^{1/2})$$

$$r_e = -k_2 C_a C_b^{1/2}$$

Stoichiometry

9

$$C_A = Ct_0 \frac{F_A T_0 p}{F_t T p_0}$$

$$C_B = Ct_0 \frac{F_B T_0 p}{F_t T p_0}$$

$$C_c = Ct_0 \frac{F_c T_0 p}{F_t T p_0}$$

$$C_D = Ct_0 \frac{F_D T_0 p}{F_t T p_0}$$

$$Ct_0 = CA_0 + CB_0 + CC_0 + CD_0$$

Catalyst Selection

7

▶ Copper Polycyclidine with Silica Oxide Inert (CuPC-Py/SiO₂)

- ▶ For conversion of propylene into acrolein
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- ▶ For conversion of acrolein into Acrylic acid
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- ▶ Diameter: 0.004m
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Mole Balances and Rate Laws

8

- ▶ $\frac{dF_a}{dw} = ra'$
- ▶ $\frac{dF_b}{dw} = rb'$
- ▶ $\frac{dF_c}{dw} = rc'$
- ▶ $\frac{dF_d}{dw} = rd'$
- ▶ $\frac{dF_e}{dw} = re'$

$$r_a = -k_1 C_a C_b$$

$$r_b = -k_1 C_a C_b$$

$$r_c = k_1 C_a C_b$$

$$r_d = k_1 C_a C_b$$

$$r_{2e, net} = k_1 C_a C_b - k_2 C_e C_b^{1/2}$$

$$r_{2B, net} = \frac{1}{2} (-k_1 C_a C_b + k_2 C_e C_b^{1/2})$$

$$r_e = -k_2 C_e C_b^{1/2}$$

Stoichiometry

9

$$C_A = Ct_0 \frac{F_A T_0 p}{F_t T p_0}$$

$$C_B = Ct_0 \frac{F_B T_0 p}{F_t T p_0}$$

$$C_c = Ct_0 \frac{F_c T_0 p}{F_t T p_0}$$

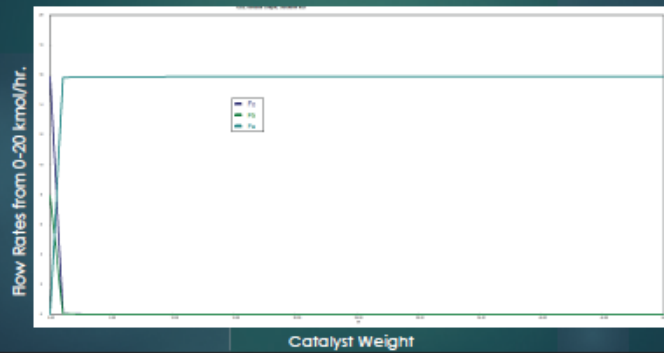
$$C_D = Ct_0 \frac{F_D T_0 p}{F_t T p_0}$$

$$Ct_0 = CA_0 + CB_0 + CC_0 + CD_0$$

Polymath Graphs (Reactor 2)

13

► Flowrate vs Weight



Polymath Graphs (Reactor 2)

14

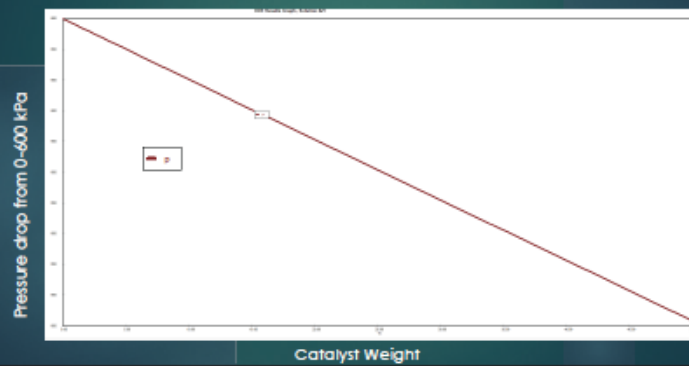
► Concentration vs. Weight



Polymath Graphs (Reactor 2)

15

► Pressure vs. Weight



Polymath Graphs (Reactor 2)

16

► Conversion vs Weight



Polymath Graphs (Reactor 2)

17

► Temperature vs Weight



Polymath Results

18

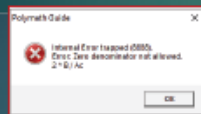
- The polymath was used to calculate the relationship the flow rates, concentration, temperature and pressure. Using supporting equations, polymath was able produce the desired value of Acrylic Acid. This value was assumed to equal the initial flowrate of acrolein.
- Although the correct value for Acrylic Acid was produced, the graphs showed that the catalyst ran out fast.
- Overall, the flow rate and concentration relationship to weight were similar.

Polymath (Reactor 1)

1. **Minic Features**
 1-1 **EF84(00)** = 1A
 1-2 **EF84(01)** = 1B44 = *polydora* *lanceolata*
 1-3 **EF84(02)** = 1C = *polydora* *lanceolata*
 1-4 **EF84(03)** = 1D
 1-5 **EF84(04)** = 1E = *amphipora* *lanceolata*
 1-6 **EF84(05)** = 1F
 1-7 **EF84(06)** = 1G = *amphipora* *lanceolata*
 1-8 **EF84(07)** = 1H = *amphipora* *lanceolata*
 1-9 **EF84(08)** = 1I = *amphipora* *lanceolata*
 1-10 **EF84(09)** = 1J = *amphipora* *lanceolata*
 1-11 **EF84(10)** = 1K = *amphipora* *lanceolata*
 1-12 **EF84(11)** = 1L = *amphipora* *lanceolata*
 1-13 **EF84(12)** = 1M = *amphipora* *lanceolata*
 1-14 **EF84(13)** = 1N = *amphipora* *lanceolata*
 1-15 **EF84(14)** = 1O = *amphipora* *lanceolata*
 1-16 **EF84(15)** = 1P = *amphipora* *lanceolata*
 1-17 **EF84(16)** = 1Q = *amphipora* *lanceolata*
 1-18 **EF84(17)** = 1R = *amphipora* *lanceolata*
 1-19 **EF84(18)** = 1S = *amphipora* *lanceolata*
 1-20 **EF84(19)** = 1T = *amphipora* *lanceolata*
 1-21 **EF84(20)** = 1U = *amphipora* *lanceolata*
 1-22 **EF84(21)** = 1V = *amphipora* *lanceolata*
 1-23 **EF84(22)** = 1W = *amphipora* *lanceolata*
 1-24 **EF84(23)** = 1X = *amphipora* *lanceolata*
 1-25 **EF84(24)** = 1Y = *amphipora* *lanceolata*
 1-26 **EF84(25)** = 1Z = *amphipora* *lanceolata*
 1-27 **EF84(26)** = 1AA = *amphipora* *lanceolata*
 1-28 **EF84(27)** = 1AB = *amphipora* *lanceolata*
 1-29 **EF84(28)** = 1AC = *amphipora* *lanceolata*
 1-30 **EF84(29)** = 1AD = *amphipora* *lanceolata*
 1-31 **EF84(30)** = 1AE = *amphipora* *lanceolata*
 1-32 **EF84(31)** = 1AF = *amphipora* *lanceolata*
 1-33 **EF84(32)** = 1AG = *amphipora* *lanceolata*
 1-34 **EF84(33)** = 1AH = *amphipora* *lanceolata*
 1-35 **EF84(34)** = 1AI = *amphipora* *lanceolata*
 1-36 **EF84(35)** = 1AJ = *amphipora* *lanceolata*
 1-37 **EF84(36)** = 1AK = *amphipora* *lanceolata*
 1-38 **EF84(37)** = 1AL = *amphipora* *lanceolata*
 1-39 **EF84(38)** = 1AM = *amphipora* *lanceolata*
 1-40 **EF84(39)** = 1AN = *amphipora* *lanceolata*
 1-41 **EF84(40)** = 1AO = *amphipora* *lanceolata*
 1-42 **EF84(41)** = 1AP = *amphipora* *lanceolata*
 1-43 **EF84(42)** = 1AQ = *amphipora* *lanceolata*
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 1-45 **EF84(44)** = 1AS = *amphipora* *lanceolata*
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 1-47 **EF84(46)** = 1AU = *amphipora* *lanceolata*
 1-48 **EF84(47)** = 1AV = *amphipora* *lanceolata*
 1-49 **EF84(48)** = 1AW = *amphipora* *lanceolata*
 1-50 **EF84(49)** = 1AX = *amphipora* *lanceolata*
 1-51 **EF84(50)** = 1AY = *amphipora* *lanceolata*
 1-52 **EF84(51)** = 1AZ = *amphipora* *lanceolata*
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 1-54 **EF84(53)** = 1BB = *amphipora* *lanceolata*
 1-55 **EF84(54)** = 1BC = *amphipora* *lanceolata*
 1-56 **EF84(55)** = 1BD = *amphipora* *lanceolata*
 1-57 **EF84(56)** = 1BE = *amphipora* *lanceolata*
 1-58 **EF84(57)** = 1BF = *amphipora* *lanceolata*
 1-59 **EF84(58)** = 1BG = *amphipora* *lanceolata*
 1-60 **EF84(59)** = 1BH = *amphipora* *lanceolata*
 1-61 **EF84(60)** = 1BI = *amphipora* *lanceolata*
 1-62 **EF84(61)** = 1BJ = *amphipora* *lanceolata*
 1-63 **EF84(62)** = 1BK = *amphipora* *lanceolata*
 1-64 **EF84(63)** = 1BL = *amphipora* *lanceolata*
 1-65 **EF84(64)** = 1BM = *amphipora* *lanceolata*
 1-66 **EF84(65)** = 1BN = *amphipora* *lanceolata*
 1-67 **EF84(66)** = 1BO = *amphipora* *lanceolata*
 1-68 **EF84(67)** = 1BP = *amphipora* *lanceolata*
 1-69 **EF84(68)** = 1BQ = *amphipora* *lanceolata*
 1-70 **EF84(69)** = 1BR = *amphipora* *lanceolata*
 1-71 **EF84(70)** = 1BS = *amphipora* *lanceolata*
 1-72 **EF84(71)** = 1BT = *amphipora* *lanceolata*
 1-73 **EF84(72)** = 1BU = *amphipora* *lanceolata*
 1-74 **EF84(73)** = 1BV = *amphipora* *lanceolata*
 1-75 **EF84(74)** = 1BW = *amphipora* *lanceolata*
 1-76 **EF84(75)** = 1BX = *amphipora* *lanceolata*
 1-77 **EF84(76)** = 1BY = *amphipora* *lanceolata*
 1-78 **EF84(77)** = 1BZ = *amphipora* *lanceolata*
 1-79 **EF84(78)** = 1CA = *amphipora* *lanceolata*
 1-80 **EF84(79)** = 1CB = *amphipora* *lanceolata*
 1-81 **EF84(80)** = 1CC = *amphipora* *lanceolata*
 1-82 **EF84(81)** = 1CD = *amphipora* *lanceolata*
 1-83 **EF84(82)** = 1CE = *amphipora* *lanceolata*
 1-84 **EF84(83)** = 1CF = *amphipora* *lanceolata*
 1-85 **EF84(84)** = 1CG = *amphipora* *lanceolata*
 1-86 **EF84(85)** = 1CH = *amphipora* *lanceolata*
 1-87 **EF84(86)** = 1CI = *amphipora* *lanceolata*
 1-88 **EF84(87)** = 1CJ = *amphipora* *lanceolata*
 1-89 **EF84(88)** = 1CK = *amphipora* *lanceolata*
 1-90 **EF84(89)** = 1CL = *amphipora* *lanceolata*
 1-91 **EF84(90)** = 1CM = *amphipora* *lanceolata*
 1-92 **EF84(91)** = 1CN = *amphipora* *lanceolata*
 1

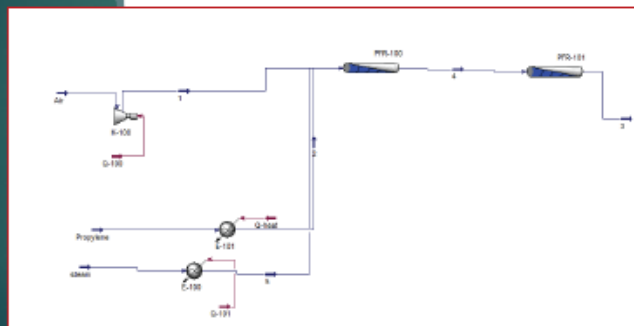
[illegible]

Polymath Results (Reactor 1)



- ▶ Code was in a continuous loop
- ▶ Received Errors
- ▶ Graphs and reports were unable to be retrieved

Aspen HYSYS Simulation



Aspen HYSYS Simulation cont.

22

Name	Value
Compressor Speed (rpm)	6-180
Power (kW)	175.96
Capacity (act head vol flow) (ACT_vol/N)	1999.62
Adiabatic Efficiency	75
Polytropic Efficiency	76.8647
Compressor Volume (m3)	6
Delta T (K)	293.103
Delta P (MPa)	486.7
Polytropic Head (m)	19407.6
Adiabatic Head (m)	16202.6
Dynamic Head (m)	15887.8
Polytropic Fluid Head (kJ/kg)	193.125
Adiabatic Fluid Head (kJ/kg)	173.395
Dynamic Fluid Head (kJ/kg)	169.125
Polytropic Head Factor	1.69255
Polytropic Exponent	1.32171
Isentropic Exponent	1.38277
Dynamic Delta P	
RC-Typical Design Speed	
RC-Isobaric Efficiency	
RC-Number of Cylinders	0
RC-Rev (m)	
RC-Stroke (m)	

Efficiency: 75+%

Economic Analysis

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Product Sales: \$220/MT

Material Pricing

- Raw Materials
 - Propylene \$1.2M/ton
 - Water \$0.0015/kg
 - Air \$0/kg
- Catalyst
 - $\text{VMO}_2\text{O}_{11}$ ~ \$350/kg
 - CuPcPy/SiO_2 ~ \$30/kg

Item	Cost
Total CAPCOST	\$2.5MM
Total Operating	\$1.5MM
Raw Materials	\$57M
Utilities Cost	\$36M
Equipment Cost	\$856M
Installation Cost	\$82M

Safety Considerations

24

- ▶ Correct PPE
- ▶ Reaction calorimetry (to avoid runaway)
- ▶ Minimize chemical exposures to the air
- ▶ Propylene:
 - Can cause burns, severe injury or frostbite
 - Extremely flammable
 - Spills may require downwind evacuation



- ▶ Acrolein:
 - toxic to humans following inhalation, oral or dermal exposures.
- ▶ Acrylic Acid:
 - Corrosive to metals
 - Polymerize under long exposure to heat

Conclusion

25

Reactor 2	F_C (kmol/hr)	F_B (kmol/hr)	F_E (kmol/hr)
Initial Value	15.89	7.95	0
Final Value	0.0098	0.009	15.88

Conclusion

26

- ▶ For Reactor 2, Polymath calculated to correct value of acrylic acid which was assumed to be the same as the initial flowrate of acrolein.
- ▶ For Reactor 1, there were inaccurate data / code errors
- ▶ Due to the design parameters, Aspen was unable to produce acrylic acid.
- ▶ Recommendations:
 - ▶ Include side reactions
 - ▶ Include the separation processes

27

Questions?

- ▶ [OPIS safety summary], ARMA, 2012/08/20
- ▶ [Mitsubishi Weld - 79-103-QPS 2013000 - Acid Acrylic.docx \(arkema.com\)](#)
- ▶ "Acrylic acid market analysis," Grand view Research, February 2014 [https://www.grandviewresearch.com/industry-analysis/acrylic-acid-market](#)
- ▶ Peret Sanchez, Amouy, et al., "Simulation of the Acrylic Acid Production," *Scienc. catalytic*, 2019, [https://doi.org/10.1016/j.scata.2019.05.001](#)
- ▶ Tichy, Jesse, "Oxidation of Acrolein to Acrylic Acid over Vanadium-Molybdenum Oxide Catalysts," *Bavler Enhanced Review*, 1992, [https://www.bavler.com/industry-and-technology/2022/07/20/oxidation-of-acrolein-to-acrylic-acid-over-vanadium-molybdenum-oxide-catalysts/](#)
- ▶ Quillix, Hageman, et al., "Steady State Simulation of Acrylic Acid Production by Catalytic Oxidation of Propylene," *Developmental Catalysis*, 2001, [https://doi.org/10.1016/S0924-6460\(00\)00020-9](#)
- ▶ Tichy, Jesse, et al., "Highly Diluted Copper in a Silica Matrix as Active Catalyst for Propylene Oxidation to Acrolein," *Catalysis Letters*, vol. 131, no. 1-2, 2009, pp. 49-53, [https://doi.org/10.1007/s10562-009-9997-9](#)
- ▶ Acrolein - Epa.gov, [https://www.epa.gov/air-pollution/acrolein](#)
- ▶ "Acrylic Acid," National Center for Biotechnology Information, PubChem Compound Database, U.S. National Library of Medicine, [https://pubchem.ncbi.nlm.nih.gov/compound/Acrylic-Acid](#)
- ▶ "Propylene," [ChemicalSafetyFacts.org](#), 15 Feb. 2022, [https://www.chemicalsafetyfacts.org/propylene/](#)

BELOW AVERAGE



DEPARTMENT OF CHEMICAL ENGINEERING
CHEG 3306-P02: KINETICS AND REACTOR DESIGN
COURSE ASSIGNMENT GRADING AND OUTCOME ASSESSMENT
SHEET FOR SPRING 2022 SEMESTER

ABET OUTCOME 2: Show an ability to design a system, a component, or a process to meet desired need within constraints.

Group Name: 6 Date: 05/10/2022

Title of Assignment: Acrylic Acid Production

Competency Area	Points	Grade
Presentation, Design (Outcome 2.3)	85	59
Determine the type of reactor and the phase of the reactants/products.	5	5
Determine the operating temperature and pressure.	5	5
Determine reactor volume, number of tubes, and catalyst weight required	10	7
Presents an accurate algorithm of equations	5	3
Meet design constraints given in the problem statement.	10	6
Has simulation results from Polymath for material and energy balances	15	10
Has an ASPEN reactor simulation	15	10
Includes a cost analysis	5	2
Dressed for occasion, speak with confidence, answers questions professionally	5	3
Determine the heat required/produced during process	5	3
Research common safety procedures require for the reactor materials.	5	5
Report, Content (Outcome 2.2)	85	72
Contains the required sections:	5	5
At least ten pages, double-spaced, 12 pt Times New Roman font; Grammar	5	3
Contains all design findings in the Project Summary	10	7
Contains an adequate reaction mechanism explanation based on chosen catalyst	10	7
Introduces the topic of acrylic acid production	5	5
Explains/discusses tables and graphs in the report	10	10
Details a full design of the reactor operation including design equations and parameters	15	15
Cost Analysis is explained in report	10	10
Concludes by listing design challenge, approach to solving, and the solution achieved	5	5
Write a full technical report of literature review without plagiarism.	10	5
Group Participation Grade (input from group members; Outcome 2.3)	30	
Handwritten Algorithm	20	
Background Report (Outcome 2.1)	30	
Simulation	50	46
TOTAL POINTS	300	

NOTES:

Presentation:

- Group member is clearly agitated.
- What is T_b in the EB?
- $W_1 = 2300 \text{ kg}$
 $W_2 = 1,400 \text{ kg}$
- Too many slides for presentation
- Aspen was incomplete

- Calculated # of tubes by hand with a value less than 1.0.
- Did not explain calculation method.
- Did not understand all information presented in their slides.

- Missing reactions?
- Cannot see values in graphs.
- Did not type equations

Reactor Design Project

Group 6

Najam Din, Kiara Graham, & Ezzy Tatmon

Introduction

- Equipment:
 - ASPEN HYSYS Simulation
 - Polymath
- Purpose:
 - ASPEN HYSYS Simulation- address engineering challenges within flow models, gas processes, and refineries.
 - Polymath- defining unknown parameters within a system

Objective

To stimulate a reactor design to produce acrylic acid from the oxidation of propylene using Aspen HYSYS and Polymath Simulations

Project Statement/ Details^[1]

Given:

- First reactor propylene is converted into acrolein
- Second reactor acrolein is converted into acrylic acid
- Maximum of 10,000 metric tons of acrylic acid per year
- Propylene has 600 kPa and 30°C available
- 550 kPa of steam is fed into the reactor with a composition of 40 mole%
- Compressed air supplies oxygen to reactor

Design Specifications^[1]

- Assume a yield of 75% or greater of acrylic acid must be achieved
- Assume turbine efficiency of 75% and motor efficiency of 90%
- Assume reactor tube lengths: 45mm Inner Diameter, 50mm Outer Diameter, and 5m Long
- O_2/C_3H_6 feed ratio is 2.5
- Side reactions may occur

Reactor Selection^[2]

Packed Bed Reactor (PBR)

- Used primarily in homogenous reactions with a catalyst

Advantages:

- High conversion per unit mass
- Low operating cost
- Continuous operation

Disadvantages:

- Poor temperature control
- Undesired thermal gradient



Materials Background^[3,4,5]

Propene

- Also called propylene, C_3H_6
- Colorless gas
- Odor similar to petroleum

Hazard(s):

- Highly flammable and can cause explosion

Acrylic Acid

- Colorless liquid
- Acrid odor
- Corrosive to metals and tissue

Hazard(s):

- If large amounts swallowed, it can be deadly

Materials Background^[6,7]

Acrolein

- Also called propylene aldehyde, C_3H_4O
- Liquid that is clear of yellow
- Horrible odor
- Used as a pesticide
- Soluble in water and burns easily

Hazard(s):

- Highly toxic and reactive
- Cause irritation to the eyes
- Inhaling high amounts can cause damage to the lungs and respiratory system that may cause death

Catalyst Selection^[8]

Bismuth Molybdate ($Bi_2Mo_3O_{12}$)

- Found as a gray crystal or yellow powder
- Used as a catalyst for the oxidation of propylene to produce acrylic acid
- Process possible through dehydration

Reaction Mechanism^[8]

Reactor #1

A- C_3H_6

B- O_2

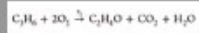
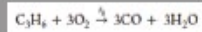
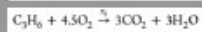
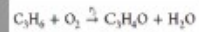
C- C_3H_4O

D- H_2O

E- CO_2

F- CO

G- C_2H_4O



Reaction Mechanism^[8]

Reactor #2

A- C_3H_4O

B- O_2

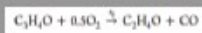
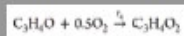
C- $C_3H_4O_2$

D- CO

E- C_2H_4

F- H_2O

G- $C_2H_4O_2$



Mole Balances & Rate Laws^[8]

Reactor #1 and #2:

- $dF_A/dW = r_A$
- $dF_B/dW = r_B$
- $dF_C/dW = r_C$
- $dF_D/dW = r_D$
- $dF_E/dW = r_E$
- $dF_F/dW = r_F$
- $dF_G/dW = r_G$

$$r_j = \frac{k_j P_i^* k_{\text{reox}} P_{O_2}}{K_{pp} P_{pp} + K_{AC} P_{AC} + k_{\text{reox}} P_{O_2}}$$

$$K_{pp} = k_1 + 2 \cdot k_3 + 4 \cdot k_5 + 6 \cdot k_8 + 9 \cdot k_9$$

$$K_{AC} = k_4 + k_6$$

$$k_j = \exp\left(k_{0,j} - E_{A,j}^* \left(\frac{T_{ref}}{T} - 1\right)\right)$$

Pressure Drop & Catalyst Weight^[9]

PBR:

- $\frac{dF_A}{dW} = r'_A$
- $W = \rho_B - V = \rho_c(1 - \phi)W$
- $-r'_A \frac{dW}{dW} = r'_A$
- $\frac{dF_A}{dW} = r'_A$

Catalyst Weight: $W = zA_c \rho_c = zA_c(1 - \phi)\rho_c$

ρ_c = bulk density

ρ_c = solid catalyst density

ϕ = porosity (void fraction)

$(1 - \phi)$ = solid fraction

Pressure Drop with Catalyst Weight: $\frac{dP}{dW} = -\frac{r'_A \rho_c T}{\rho_c(1 - \phi) T \rho_c} \frac{r'_A}{r'_A}$

$$\rho_c = \frac{\rho}{(1 - \phi)} \left[\frac{150(1 - \phi)^2}{d_p} + 1.75 \right]$$

$$\text{Let } \alpha = \frac{150}{d_p} \frac{1}{\rho_c}$$

$$\frac{dP}{dW} = -\frac{\alpha T r'_A}{2\rho_c T \rho_c}$$

$$\beta = \frac{\alpha}{2\rho_c}$$

$$\frac{d\left(\frac{P}{P_0}\right)}{dW} = -\frac{\beta}{2} \frac{T}{T_0} (1 + \alpha T)$$

$$\text{Therefore, } \frac{dP}{dW} = -\frac{\beta}{2} \frac{T}{T_0} (1 + \alpha T)$$

Energy Balance^[9]

$$\frac{dT}{dW} = \frac{\frac{U}{\rho_p} (T_a - T_b) + r'_A \Delta H_{rx}(T)}{\sum F_i C_{pi}}$$

U= overall heat-transfer coefficient (J/m²*s*K)

T= temperature (K)

ΔH_{rx} = heat of reaction (J/mol A)

r'_A = rate of reaction (kmol/hr)

C_{pi} = mean heat capacity of species i (J/mol/K)

Polymath

Reactor 1

Weight of catalyst is 2300kg for reactor 1

$$F_{a0} = 353.0 \frac{\text{kmol}}{\text{hr}}$$

$$F_{b0} = 882.0 \frac{\text{kmol}}{\text{mol}}$$

$$F_{c0} = F_{d0} = F_{e0} = F_{f0} = F_{g0} = 0$$

$$F_a = 2.09 \frac{\text{kmol}}{\text{hr}}$$

$$F_b = 339.13 \frac{\text{kmol}}{\text{hr}}$$

$$F_c = 16.86 \frac{\text{kmol}}{\text{hr}}$$

$$F_d = 276.3 \frac{\text{kmol}}{\text{hr}}$$

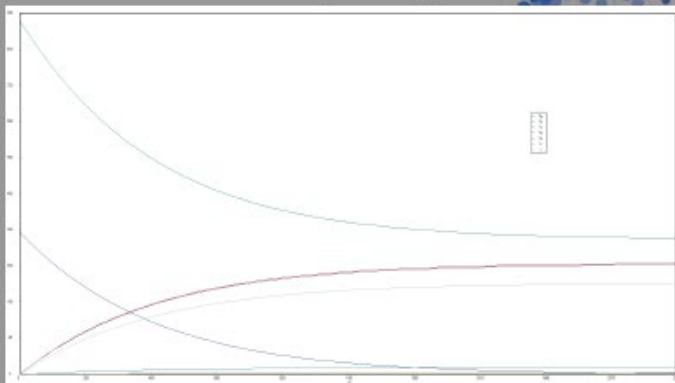
$$F_e = 273.0 \frac{\text{kmol}}{\text{hr}}$$

$$F_f = 3.31 \frac{\text{kmol}}{\text{hr}}$$

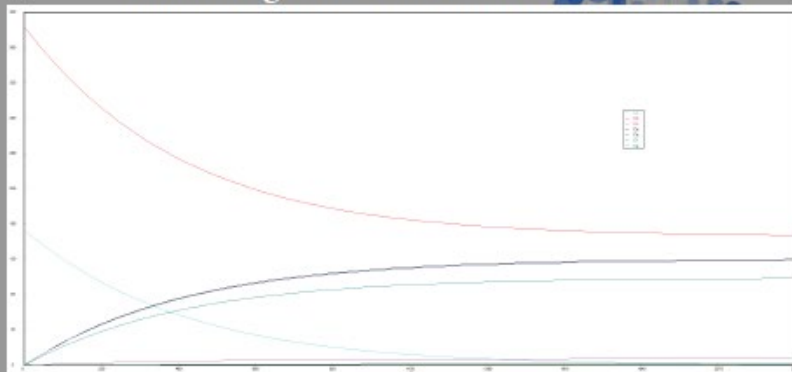
$$F_g = 226.4 \frac{\text{kmol}}{\text{hr}}$$

[illegible]

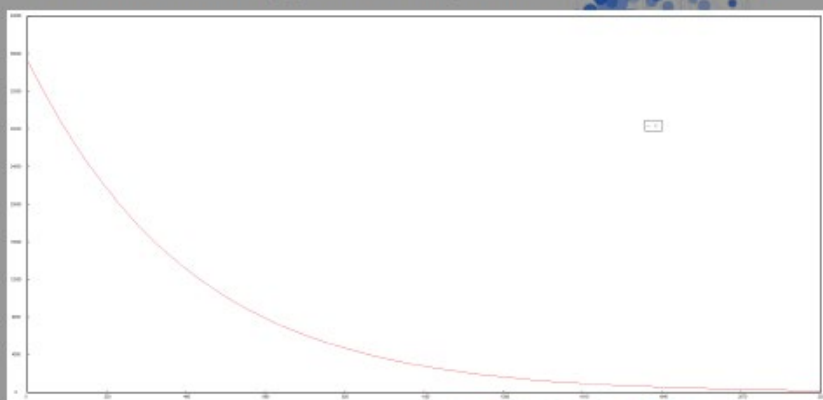
Flow Rates Vs Catalyst Weight For Reactor 1



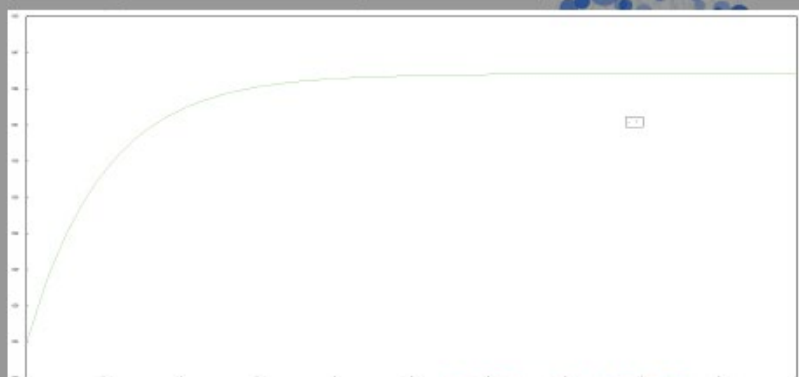
Concentration Vs Catalyst Weight of All Species Including Side Reactions for Reactor 1



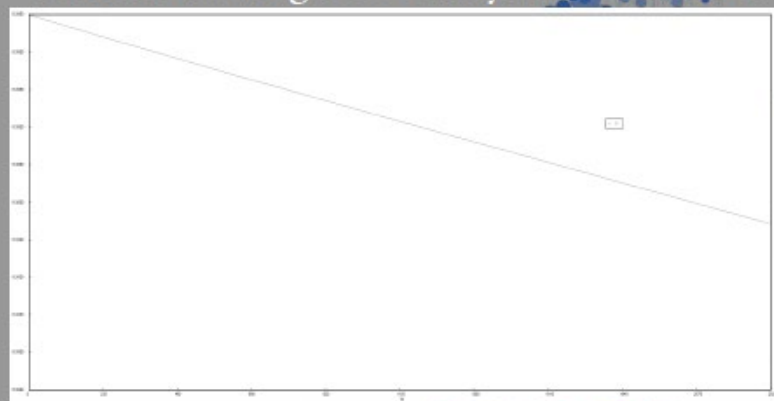
Conversion of Propylene Vs Weight of Catalyst for Reactor 1



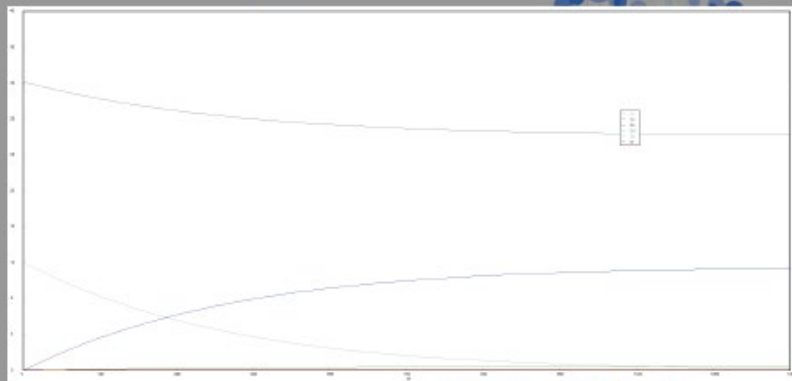
Temperature Vs Weight of Catalyst for Reactor 1



Pressure Vs Weight of Catalyst for Reactor 1



Weight of Catalyst for Reactor 2: 1400kg



A graph of the function $f(x) = 1 - e^{-x/2}$ for $x \in [0, 20]$. The x-axis is labeled from 0 to 20 in increments of 5. The y-axis is labeled from 0 to 1 in increments of 0.2. The curve starts at the origin (0,0) and increases, approaching the horizontal line $y=1$ as x increases. A label $f(x)$ is placed near the curve.

Cost Estimation

- Propylene: \$0.48/kg– \$52,800,000
- Labor cost: Assume 500 employees get paid \$60,000– \$30,000,000
- Heat Exchanger Cost:

$$e^{8.596+0.153 \ln(A)+0.06(\ln(A)^2)}$$

$$A = \frac{N \cdot \pi}{4 \cdot D^2}$$

1st Reactor: D= 45mm, N=0.0319, A=1.237m²

2nd Reactor: D=45mm, N=0.0257, A= 99.67 m²

- 1st Reactor: \$11619.42
- 2nd Reactor: \$38976.53

Conclusion

- The process system went well but some challenges occurred along the way.
- Aspen Simulation was unable to be completed
- Many cost estimation parameters were unable to be calculated
- Recommendations:
- Asking for help when issues first arise
- Making sure to look at more than one research paper before beginning calculations

References

- [1] Reeves, S. (2022). General Project Information, Canvas. Retrieved May 3, 2022, from <https://canvas.mercer.edu/Courses/16174/Assignments/General-Information/Module/Item/Id=975413>
- [2] Scott H. Folger. (2019). Packed Bed Reactors (PBRs). Retrieved April 25, 2022, from <https://opentext.umd.edu/chem-262/elementary/lectures/pbrs/index.html>
- [3] Zhai, Z., Witzchant, M., Licht, R. B., & Bell, A. T. (2015). Effects of catalyst crystal structure on the oxidation of propene to acrolein. Redirection. Retrieved April 29, 2022, from <https://doi.org/10.1016/j.cattod.2015.06.011>
- [4] Zhai, Z., Witzchant, M., Licht, R. B., & Bell, A. T. (2016). Effects of catalyst crystal structure on the oxidation of propene to acrolein. Science Direct. Retrieved May 3, 2022, from <https://www.sciencedirect.com/science/article/pii/S0926860916300490>
- [5] Chanda, S., & Mehendale, H. M. (2005). Acrylic Acid. Redirection. Retrieved April 29, 2022, from <https://doi.org/10.1015/B96-12-342400-00024-7>
- [6] National Center for Biotechnology Information. (2022). PubChem Compound Summary for CID 7847, Acrolein. Retrieved April 29, 2022 from <https://pubchem.ncbi.nlm.nih.gov/compound/Acrolein>
- [7] Health, D. (2015). Acrolein. Delaware Health and Social Services. Retrieved May 3, 2022, from <https://www.dhs.de/delaware.gov/health/chemicals/acrolein.pdf>
- [8] Garsen, G., & Freund, H. (2019). Kinetic modeling of the partial oxidation of propylene to acrolein: A systematic procedure for parameter estimation based on non-isothermal data. Industrial & Engineering Chemistry Research, 58(5), 1857-1874. <https://doi.org/10.1021/acs.iecr.8b05583>
- [9] Fogler, H.S. (2016). Elements of chemical reaction engineering 5th Edition, Prentice Hall, Polymath
- Aspen HYSYS Simulation

**CHEG 3306-02: KINETICS AND REACTOR DESIGN
SPRING 2022 SEMESTER**

Title of Assignment: EXAM II

TOPICS COVERED IN EXAM II

EXAM II covered the following topics:

1. Multiple Reactions
2. Selectivity
3. Desired/Undesired products
4. Optimal operating conditions
5. Energy Balance
6. Heat Calculations

DEPARTMENT OF CHEMICAL ENGINEERING
CHEG 3306-P02: KINETICS AND REACTOR DESIGN
COURSE ASSIGNMENT GRADING AND OUTCOME ASSESSMENT
SHEET FOR SPRING 2022 SEMESTER

ABET OUTCOME 1: Show an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.

ABET OUTCOME 2: Show an ability to design a system, a component, or a process to meet desired need within constraints.

Name: _____

Title of Assignment: Exam 2b Date: 04/28/2022

Competency Area	Max for this Assignment	Your Score
Outcome 1.1 – Identify and Formulate - Derive mole balance equation for various reactors. - Combine rate laws, mole balances, and stoichiometry to solve for volume, concentration, or flow rate. - Calculate conversion and concentration using appropriate equations.		
Outcome 2.1 – Selection/Safety - Evaluate the selectivity of products in reactions and choose feed location of raw materials. - Increase desired product for single and multiple reactants by selecting appropriate reactor and feed conditions. - Recognize the importance for safety and determine the risk associated with gas releases from reactors		
TOTAL	150	

$$X_{EB} = \frac{\sum \Theta_i C_{P_i} (T - T_0)}{-\Delta H_{Rx}}$$

$$T = T_0 + \frac{(-\Delta H_{Rx})X}{\sum \Theta_i C_{P_i}}$$

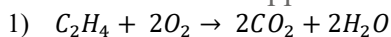
$$\frac{dT}{dW} = \frac{\frac{Ua}{\rho_B} (T_a - T) + r'_A \Delta H_{Rx}(T)}{F_{A0} (\sum \Theta_i C_{P_i} + \Delta C_P X)}$$

$$\frac{d\hat{E}_{evc}}{dV} = \frac{Ua(T_a - T) + \sum r_{ij} \Delta H_{Rxij}}{\sum F_i C_{P_i}}$$

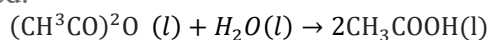
$$\frac{dT}{dV} = \frac{Ua(T_a - T) + r_A \Delta H_{Rx}(T)}{F_{A0} (\sum \Theta_i C_P + \Delta C_P X)}$$

$$\frac{dT}{dW} = \frac{\frac{Ua}{\rho_B} (T_a - T) + r'_A \Delta H_{Rx}(T)}{\sum F_i C_{P_i}}$$

Problem 1: (30 pts). The production of ethylene oxide occurs from the reaction of ethylene and oxygen; however, carbon dioxide and water is produced in a side reaction as shown below. Provide net rates of disappearance for each compound.



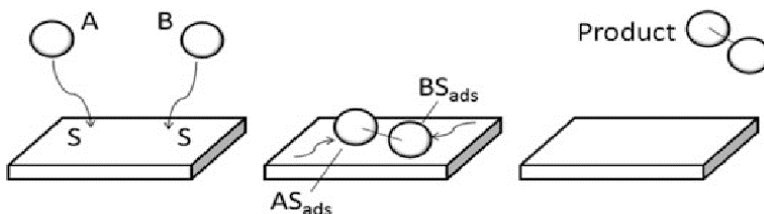
Problem #2: 15 pts Acetic anhydride reacts violently with water to make acetic acid; therefore, the reaction must be controlled.



- What type of reaction is occurring? _____
- Is this reaction homogeneous or heterogeneous? (Simply circle your answer).
- Is this reaction endothermic or exothermic? (Simply circle your answer).

Problem #3(15 pts) Answer the following set of questions.

- Runaway reactions are caused by which of the following types of reactions?
 - Isothermal
 - Endothermic
 - Exothermic
 - Adiabatic
- For exothermic reactions, what does a negative value of heat of reaction mean?
 - Isothermal
 - Endothermic
 - Exothermic
 - Adiabatic
- The following image refers to the _____ mechanism.



Problem #4: (30 pts) A reversible, liquid phase reaction has $A + B \leftrightarrow 2C$ occurs in an adiabatic CSTR. The feed contains 100 mol/h of A and 200 mol/h of B. The initial reactor temperature is 450K. The heat capacities of reactant A and B is noted as 42 cal/mol K and 60 cal/mol K respectively. At 298K, the equilibrium constant is 12,000 and the heat of reaction is -4,000 cal/mol.

- a. Assuming $\Delta C_p = 0$ and a conversion of 70%, calculate the *adiabatic equilibrium temperature*?
- b. What is the *equilibrium conversion* if the exit temperature is 1000K?

Problem #5: 35 pts A second order, liquid phase reaction $A + B \rightarrow C$ occurs in a jacketed CSTR. The reaction is assumed as elementary. The feed contains 1.5 kmol/m^3 of A and 1.0 kmol/m^3 of B with an initial volumetric flow rate of $0.002 \text{ m}^3/\text{s}$. A coolant is used at a constant 283K . The heat of reaction is $-6.15 \frac{\text{KJ}}{\text{kmol of A}}$.

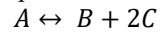
Additional information:

$$X = 0.85; \quad U = 2.0 \text{ KJ/m}^2 \cdot \text{s} \cdot \text{K}; \quad C_{PA} = 30 \text{ J/(mol} \cdot \text{K)}; \quad C_{PB} = 18 \text{ J/(mol} \cdot \text{K)}; \quad C_{PC} = 22 \text{ J/(mol} \cdot \text{K)} \quad k = 0.01 \frac{\text{m}^3}{\text{kmol} \cdot \text{s}}$$

- Determine the reactor volume of the CSTR.
- Calculate the heat transfer area necessary for a reactor temperature of 300K ?
- How much heat is being removed during the reaction?

Problem #6: 30 pts

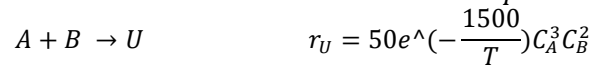
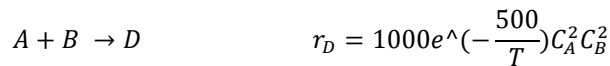
The following first order, elementary reaction takes place in a catalytic membrane reactor (CMR):



Component B diffuses through the membrane and component C is the desired product. Unfortunately, component A also diffuses through the membrane. :

- Provide mole balance equations for each compound in terms of flow rate.
- A rate of disappearance for component A.
- Transport equations (kinetics) for the components that diffuse through the membrane.

Problem #7: 25 pts Consider the following parallel reactions where the desired product is achieved in the first reaction.



- Derive and simplify an expression for the selectivity of D to U.
- To maximize the production of the desired products, what setting is required for the temperature?
- What type of reactor should we use? Sketch an image to support your suggestion.

ABOVE AVERAGE

DEPARTMENT OF CHEMICAL ENGINEERING
CHEG 3306-P02: KINETICS AND REACTOR DESIGN
COURSE ASSIGNMENT GRADING AND OUTCOME ASSESSMENT SHEET
FOR SPRING 2022 SEMESTER

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ABET OUTCOME 2: Show an ability to design a system, a component, or a process to meet desired need within constraints.

Name: Nina Patthammavong

Title of Assignment: Exam 2b

Date: 04/28/2022

Competency Area	Max for this Assignment	Your Score
Outcome 1.1 – Identify and Formulate - Derive mole balance equation for various reactors. - Combine rate laws, mole balances, and stoichiometry to solve for volume, concentration, or flow rate. - Calculate conversion and concentration using appropriate equations.	85	74
Outcome 2.1 – Selection/Safety - Evaluate the selectivity of products in reactions and choose feed location of raw materials. - Increase desired product for single and multiple reactants by selecting appropriate reactor and feed conditions. - Recognize the importance for safety and determine the risk associated with gas releases from reactors	65	60
TOTAL	150	134

$$\dot{Q} - \dot{W}_s + \sum_{i=1}^n F_{i0} H_{i0} - \sum_{i=1}^n F_i H_i = \frac{d\hat{E}_{sys}}{dt}$$

$$X_{EB} = \frac{\left(\frac{UA}{F_{A0}} (T - T_a) \right) + \sum \Theta_i C_{Pi} (T - T_{i0})}{-\Delta H_{Rx}}$$

$$X_{EB} = \frac{\sum \Theta_i C_{Pi} (T - T_0)}{-\Delta H_{Rx}}$$

$$T = T_0 + \frac{(-\Delta H_{Rx})X}{\sum \Theta_i C_{Pi}}$$

$$\frac{dT}{dV} = \frac{Ua(T_a - T) + \sum r_{ij} \Delta H_{Rxij}}{\sum F_i C_{Pi}}$$

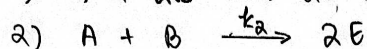
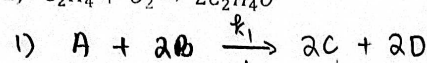
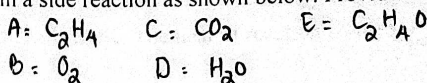
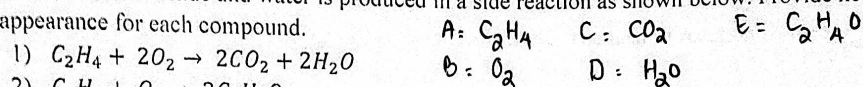
$$\frac{dT}{dW} = \frac{\frac{Ua}{\rho_B} (T_a - T) + r'_A \Delta H_{Rx}(T)}{\sum F_i C_{Pi}}$$

$$\frac{dT}{dW} = \frac{\frac{Ua}{F_{A0}} (T_a - T) + r'_A \Delta H_{Rx}(T)}{F_{A0} (\sum \Theta_i C_{Pi} + \Delta C_P X)}$$

$$\frac{dT}{dV} = \frac{Ua(T_a - T) + r_A \Delta H_{Rx}(T)}{F_{A0} (\sum \Theta_i C_{Pi} + \Delta C_P X)}$$

$$\frac{dT}{dV} = \frac{Ua(T_a - T) + r_A \Delta H_{Rx}(T)}{\sum F_i C_{Pi}}$$

Problem 1: (30 pts). The production of ethylene oxide occurs from the reaction of ethylene and oxygen; however, carbon dioxide and water is produced in a side reaction as shown below. Provide net rates of disappearance for each compound.



Relative rate

Reaction 1 $\frac{-r_A}{-1} = \frac{-r_B}{-2} = \frac{-r_C}{2} = \frac{-r_D}{2}$

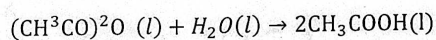
Reaction 2 $\frac{-r_A}{-1} = \frac{-r_B}{-1} = \frac{-r_E}{2}$

$(-r_A)_{Net} = (-r_A) + (-r_{2A})$

$(-r_A)_{Net} = k_1 C_A C_B^2 + k_2 C_A C_B$

$k_1 C_A C_B^2$
 $k_2 C_A C_B$
 $(-r_B)_{Net} = (-r_{1B}) + (-r_{2B})$
 $(-r_B)_{Net} = 2k_1 C_A C_B^2 + k_2 C_A C_B$
 $(-r_C)_{Net} = (-r_{1C}) + (-r_{2C})$
 $(-r_C)_{Net} = -2k_1 C_A C_B^2$
 $(-r_D)_{Net} = (-r_{1D}) + (-r_{2D})$
 $(-r_D)_{Net} = -2k_1 C_A C_B^2$
 $(-r_E)_{Net} = (-r_{2E}) + (-r_{2E})$
 $(-r_E)_{Net} = -2k_2 C_A C_B$

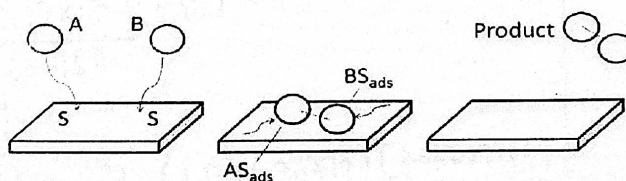
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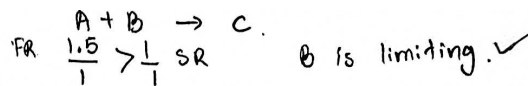


- What type of reaction is occurring? Hydration reaction.
- Is this reaction homogeneous or heterogeneous? (Simply circle your answer).
- Is this reaction endothermic or exothermic? (Simply circle your answer).

Problem #3 (15 pts) Answer the following set of questions.

- Runaway reactions are caused by which of the following types of reactions?
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 - Endothermic
 - Exothermic
 - Adiabatic
- For exothermic reactions, what does a negative value of heat of reaction mean?
 - Isothermal
 - Endothermic
 - Exothermic
 - Adiabatic
- The following image refers to the Lagmir-Hisenwood mechanism.





Problem #5: 35 pts A second order, liquid phase reaction $A + B \rightarrow C$ occurs in a jacketed CSTR. The reaction is assumed as elementary. The feed contains 1.5 kmol/m^3 of A and 1.0 kmol/m^3 of B with an initial volumetric flow rate of $0.002 \text{ m}^3/\text{s}$. A coolant is used at a constant 283 K . The heat of reaction is $-6.15 \frac{\text{KJ}}{\text{kmol of A}}$. $\frac{\text{mol}}{\text{vol}} = C_{B0}$

Additional information:

$$X = 0.85;$$

$$U = 2.0 \text{ KJ/m}^2 \cdot \text{s} \cdot \text{K};$$

$$C_{PA} = 30 \text{ J/(mol} \cdot \text{K)};$$

$$C_{PB} = 18 \text{ J/(mol} \cdot \text{K)};$$

$$C_{PC} = 22 \text{ J/(mol} \cdot \text{K)}$$

$$k = 0.01 \frac{\text{m}^3}{\text{kmol} \cdot \text{s}}$$

- a. Determine the reactor volume of the CSTR.

$$-r_A = k C_A C_B$$

$$C_A = C_{A0}(1-X)$$

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

$$V = \frac{F_{A0} X}{k C_{B0}(1-X) C_{A0}(1-X)}$$

$$C_B = C_{B0}(1-X)$$

$$\theta_A = \frac{C_{A0}}{C_{B0}} = \frac{1.5}{1} = 1.5$$

$$V = \frac{(1.5)(0.85)}{(0.01)(500)^2(1-0.85)(1.5-0.85)} = 0.00523 \text{ m}^3$$

- b. Calculate the heat transfer area necessary for a reactor temperature of 300 K ?

$$X = \frac{\frac{UA}{F_{A0}}(T-T_a) + (C_{PA} + C_{PB})(T-T_0)}{-\Delta H_{RX}} \rightarrow \text{missing } \theta$$

$$F_{A0} X (-\Delta H_{RX}) = UA(T-T_a) + F_{A0}(C_{PA} + C_{PB})(T-T_0)$$

$$A = \frac{F_{A0} X (-\Delta H_{RX}) - F_{A0}(C_{PA} + C_{PB})(T-T_0)}{U(T-T_a)}$$

- c. How much heat is being removed during the reaction?

b) $T = T_0 + \frac{(-\Delta H_{RX}) X}{\sum \theta_i C_{Pi}}$ ← Cannot use; not adiabatic
Should have been given.

$$T_0 = T - \frac{(-\Delta H_{RX}) X}{C_{PA} + C_{PB}}$$

$$T_0 = 300 - \frac{(-6.15 \times 10^3)(0.85)}{(30+18)}$$

$$T_0 = 191.1 \text{ K} \quad \text{Too small}$$

$$A = \frac{(1.5)(0.85)(6.15 \times 10^3) - (1.5)(30+18)(300-191.1)}{(2 \times 10^3)(300-283)}$$

$$A = \frac{7841.25 - 7840.8}{34000} = 0.0000132 \text{ m}^2$$

c) How much heat is being removed

$$Q_r = UA(T-T_a)$$

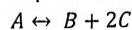
$$= (2 \times 10^3)(0.0000132)(300-283)$$

ok

$$Q_r = 0.449 \text{ J/s}$$

Problem #6: 30 pts

The following first order, elementary reaction takes place in a catalytic membrane reactor (CMR):



Component B diffuses through the membrane and component C is the desired product. Unfortunately, component A also diffuses through the membrane.:

a. Provide mole balance equations for each compound in terms of flow rate.

$$\frac{dF_A}{dV} = r_A - R_A \quad \frac{dF_B}{dV} = r_B - R_B \quad \frac{dF_C}{dV} = r_C$$

b. A rate of disappearance for component A.

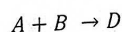
$$(-r_A)_{\text{net}} = k_A C_A - k_{-A} C_B C_C^2 = k_A \left(C_A - \frac{C_B C_C^2}{K_C} \right)$$

c. Transport equations (kinetics) for the components that diffuse through the membrane.

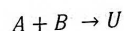
$$R_A = k_A (C_A - C_{As})$$

$$R_B = k_B (C_B - C_{Bs})$$

Problem #7: 25 pts Consider the following parallel reactions where the desired product is achieved in the first reaction.



$$r_D = 1000 e^{\left(-\frac{500}{T}\right)} C_A^2 C_B^2$$



$$r_U = 50 e^{\left(-\frac{1500}{T}\right)} C_A^3 C_B^2$$

a. Derive and simplify an expression for the selectivity of D to U.

$$S_{D/U} = \frac{r_D}{r_U} = \frac{1000 \exp\left(-\frac{500}{T}\right) C_A^2 C_B^2}{50 \exp\left(-\frac{1500}{T}\right) C_A^3 C_B^2} = 20 e^{\left(-\frac{500-1500}{T}\right)} C_A^{-1} C_B^0 = 20 e^{\frac{1000}{T}} C_A^{-1} C_B^0$$

b. To maximize the production of the desired products, what setting is required for the temperature?

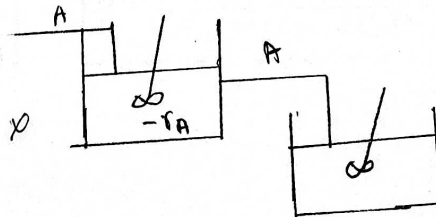
$E_U > E_D$ To maximize the products, it is required for low the temperature but not so low.

c. What type of reactor should we use? Sketch an image to support your suggestion.

$\alpha_1 < \alpha_2$. Use low concentration of A that is fed to the reactor.

$$\beta_1 = \beta_2 = 0$$

Using CSTR to dilute the feed stream.



AVERAGE

DEPARTMENT OF CHEMICAL ENGINEERING
CHEG 3306-P02: KINETICS AND REACTOR DESIGN
COURSE ASSIGNMENT GRADING AND OUTCOME ASSESSMENT SHEET
FOR SPRING 2022 SEMESTER

ABET OUTCOME 1: Show an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
 ABET OUTCOME 2: Show an ability to design a system, a component, or a process to meet desired need within constraints.

Name: Britton Andrews

Title of Assignment: Exam 2b Date: 04/28/2022

Competency Area	Max for this Assignment	Your Score
Outcome 1.1 – Identify and Formulate - Derive mole balance equation for various reactors. - Combine rate laws, mole balances, and stoichiometry to solve for volume, concentration, or flow rate. - Calculate conversion and concentration using appropriate equations.	85	52
Outcome 2.1 – Selection/Safety - Evaluate the selectivity of products in reactions and choose feed location of raw materials. - Increase desired product for single and multiple reactants by selecting appropriate reactor and feed conditions. - Recognize the importance for safety and determine the risk associated with gas releases from reactors	65	54
TOTAL	150	106

$$\dot{Q} - \dot{W}_s + \sum_{i=1}^n \dot{F}_{in} H_{in} - \sum_{i=1}^n \dot{F}_i H_i = \frac{d\hat{E}_{sys}}{dt}$$

$$X_{EB} = \frac{\left(\frac{UA}{F_{A0}} (T - T_a) \right) + \sum \Theta_i C_{P_i} (T - T_{in})}{-\Delta H_{Rx}}$$

- Heat w/ CSTR

$$X_{EB} = \frac{\sum \Theta_i C_{P_i} (T - T_0)}{-\Delta H_{Rx}}$$

$$\frac{dT}{dV} = \frac{Ua(T_a - T) + \sum r_{ij} \Delta H_{Rxij}}{\sum F_i C_{P_i}}$$

$$\frac{dT}{dV} = \frac{\frac{Ua}{\rho_B} (T_a - T) + r'_A \Delta H_{Rx}(T)}{\sum F_i C_{P_i}}$$

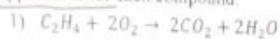
$$T = T_0 + \frac{(-\Delta H_{Rx})X}{\sum \Theta_i C_{P_i}}$$

$$\frac{dT}{dV} = \frac{\frac{Ua}{\rho_B} (T_a - T) + r'_A \Delta H_{Rx}(T)}{F_{A0} (\sum \Theta_i C_{P_i} + \Delta C_P X)}$$

$$\frac{dT}{dV} = \frac{Ua(T_a - T) + r_A \Delta H_{Rx}(T)}{F_{A0} (\sum \Theta_i C_P + \Delta C_P X)}$$

$$\frac{dT}{dV} = \frac{Ua(T_a - T) + r_A \Delta H_{Rx}(T)}{\sum F_i C_{P_i}}$$

Problem 1: (30 pts) The production of ethylene oxide occurs from the reaction of ethylene and oxygen; however, carbon dioxide and water is produced in a side reaction as shown below. Provide net rates of disappearance for each compound.



$-r_{A1} = R_1 C_A C_B^2$

$\frac{-r_A}{-1} = \frac{-r_B}{-2} = \frac{-r_C}{+2} = \frac{-r_D}{+2}$

$-r_{B1} = 2R_1 C_A C_B^2$

$-r_{C1} = 2R_1 C_A C_B^2$

$-r_{D1} = 2R_1 C_A C_B^2$

$-r_{A2} = R_2 C_A C_B$

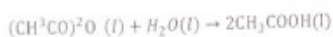
$-r_{B2} = R_2 C_A C_B$

$-r_{E2} = 2R_2 C_A C_B$

$\frac{-r_{B2}}{-1} = \frac{-r_{E2}}{+2}$

$-r_{A\text{NET}} = R_1 C_A C_B^2 + R_2 C_A C_B$
 $-r_{B\text{NET}} = 2R_1 C_A C_B^2 + R_2 C_A C_B$
 $-r_{C\text{NET}} = 2R_1 C_A C_B^2$
 $-r_{D\text{NET}} = 2R_1 C_A C_B^2$
 $-r_{E\text{NET}} = 2R_2 C_A C_B$

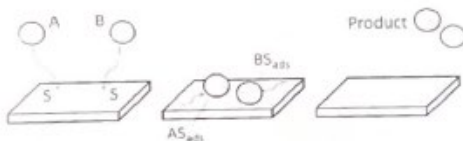
Problem #2: 15 pts Acetic anhydride reacts violently with water to make acetic acid; therefore, the reaction must be controlled.



- What type of reaction is occurring? hydrogenation
- Is this reaction homogeneous or heterogeneous? (Simply circle your answer).
- Is this reaction endothermic or exothermic? (Simply circle your answer).

Problem #3: 15 pts Answer the following set of questions.

- Runaway reactions are caused by which of the following types of reactions?
 - Isothermal
 - Endothermic
 - Exothermic
 - Adiabatic
- For exothermic reactions, what does a negative value of heat of reaction mean?
 - Isothermal
 - Endothermic
 - Exothermic
 - Adiabatic
- The following image refers to the LH mechanism. ok



$$C_{A0} = F_{A0} / v_0$$

$$1.5 \text{ kmol/m}^3 \cdot 0.002 \text{ m}^3/\text{s} \quad F_{A0} = \frac{v_0}{v} \quad \text{L. } \frac{dF_A}{dV} = -r_A$$

Problem #5: 35 pts A second order, liquid phase reaction $A + B \rightarrow C$ occurs in a jacketed CSTR. The reaction is assumed as elementary. The feed contains 1.5 kmol/m^3 of A and 1.0 kmol/m^3 of B with an initial volumetric flow rate of $0.002 \text{ m}^3/\text{s}$. A coolant is used at a constant 283 K . The heat of reaction is $-6.15 \frac{\text{kJ}}{\text{kmol of A}}$

Additional information:

$$X = 0.85;$$

$$U = 2.0 \text{ kJ/m}^2 \cdot \text{s} \cdot \text{K};$$

$$C_{PA} = 30 \text{ J/(mol K)};$$

$$C_{PB} = 18 \text{ J/(mol K)};$$

$$C_{PC} = 22 \text{ J/(mol K)}$$

$$k = 0.01 \frac{\text{m}^3}{\text{kmol} \cdot \text{s}}$$

$$v_{C0} = 0.002 \text{ m}^3/\text{s} \quad T_a = 283 \text{ K}$$

a. Determine the reactor volume of the CSTR.

$$V = \frac{F_{A0} X}{-r_A} \quad -r_A = k C_A C_B \quad C_A = C_{A0}(1-X) = 1.5 \text{ kmol/m}^3 (0.15) = 0.225 \text{ kmol/m}^3$$

$$-r_A = 0.01 \frac{\text{m}^3}{\text{kmol} \cdot \text{s}} \cdot \frac{0.002 \text{ m}^3/\text{s}}{5} \cdot \left(\frac{0.002 \text{ m}^3/\text{s}}{5} \right)^2 = 4.05 \times 10^{-10} \frac{\text{kmol}}{\text{m}^3 \cdot \text{s}}$$

$$V = \frac{1.5 \text{ kmol}}{\text{m}^3} \cdot \frac{1}{4.05 \times 10^{-10} \text{ kmol/m}^3 \cdot \text{s}} = 3.75 \times 10^{12} \text{ m}^3$$

b. Calculate the heat transfer area necessary for a reactor temperature of 300 K ?

$$X = \left(\frac{UA}{F_{A0}} (T - T_a) + \frac{\sum \theta_i C_{Pi} (T - T_0)}{-\Delta H_{rxn}} \right) \quad \sum \theta_i = -1 \quad C_{PC} = 44$$

$$V = 2000 \text{ J/m}^2 \cdot \text{s} \cdot \text{K} \quad T - T_a = T - 283 = 17$$

$$T - T_0 = T - 300 = 0$$

$$\frac{-\Delta H_{rxn} X - \sum \theta_i C_{Pi} (T - T_0) F_{A0}}{(T - T_a) U} = A$$

$$\frac{(6.15 \text{ kJ/mol}) (0.85) + 44 (T - 300) (0.002 \text{ m}^3/\text{s})}{(T - 283) 2000 \text{ J/mol} \cdot \text{K}}$$

c. How much heat is being removed during the reaction?

$$Q = ? -5$$

$$A = \frac{5227.5 \text{ J/kmol} + 72000 \text{ J/m}^3 \cdot \text{K} (T - 300)}{(T - 283 \text{ K}) 2000 \text{ J/mol} \cdot \text{K}}$$

$$T = T_0 + \frac{(-\Delta H_{rxn})}{\sum (-\theta_i)} = 300 + \frac{(6.15 \text{ J/mol})}{47}$$

$$T = 300.13$$

$$A = 0.190 \text{ m}^2$$

Problem #6: 30 pts

The following first order, elementary reaction takes place in a catalytic membrane reactor (CMR): $A \leftrightarrow B + 2C$

Component B diffuses through the membrane and component C is the desired product. Unfortunately, component A also diffuses through the membrane.

- a. Provide mole balance equations for each compound in terms of flow rate.

$$\frac{dF_A}{dV} = \dot{r}_A - R_A \quad \frac{dF_B}{dV} = \dot{r}_B - R_B \quad \frac{dF_C}{dV} = \dot{r}_C$$

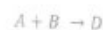
- b. A rate of disappearance for component A.

$$-r_A = k_1 C_A - k_{-1} C_B C_C^2$$

- c. Transport equations (kinetics) for the components that diffuse through the membrane.

$$\frac{dF_A}{dV} = k_1 C_A - k_{-1} C_B C_C^2 - R_A \quad \frac{dF_B}{dV} = -R_B$$

Problem #7: 25 pts Consider the following parallel reactions where the desired product is achieved in the first reaction.



$$r_D = 1000 e^{\left(-\frac{500}{T}\right)} C_A^2 C_B^2$$

Case 1: $\alpha_1 > \alpha_2$

Case 2: $\alpha_1 < \alpha_2$



$$r_U = 50 e^{\left(-\frac{1500}{T}\right)} C_A^2 C_B^2$$

Case 3: $\alpha_1 > \alpha_2$, $E_1 > E_2$

Case 4: $\alpha_1 < \alpha_2$, $E_1 > E_2$

- a. Derive and simplify an expression for the selectivity of D to U.

$$S_{D/U} = \frac{r_D}{r_U} = \frac{1000 e^{\left(-\frac{500}{T}\right)} C_A^2 C_B^2}{50 e^{\left(-\frac{1500}{T}\right)} C_A^2 C_B^2}$$

simplify -4

- b. To maximize the production of the desired products, what setting is required for the temperature?

$$\alpha_1 < \alpha_2$$

$$E_1 > E_2$$

$$\frac{-500}{20} = -25 \quad \frac{-1500}{20} = -75$$

The temperature setting needs to be low to have maximum production of desired

- c. What type of reactor should we use? Sketch an image to support your suggestion.

CSTR should be used because $\alpha_1 < \alpha_2$ which are cases 3 & 4 but case 4 is for reactions @ high temperatures therefore we should use case 3



Compare -5

BELOW AVERAGE

DEPARTMENT OF CHEMICAL ENGINEERING
CHEG 3306-P02: KINETICS AND REACTOR DESIGN
COURSE ASSIGNMENT GRADING AND OUTCOME ASSESSMENT SHEET
FOR SPRING 2022 SEMESTER

ABET OUTCOME 1: Show an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
 ABET OUTCOME 2: Show an ability to design a system, a component, or a process to meet desired need within constraints.

Name: Maya Speaks

Title of Assignment: Exam 2b.

Date: 04/28/2022

Competency Area	Max for this Assignment	Your Score
Outcome 1.1 – Identify and Formulate - Derive mole balance equation for various reactors. - Combine rate laws, mole balances, and stoichiometry to solve for volume, concentration, or flow rate. - Calculate conversion and concentration using appropriate equations.	85	57
Outcome 2.1 – Selection/Safety - Evaluate the selectivity of products in reactions and choose feed location of raw materials. - Increase desired product for single and multiple reactants by selecting appropriate reactor and feed conditions. - Recognize the importance for safety and determine the risk associated with gas releases from reactors	65	44
TOTAL	150	101

$$\dot{Q} - \dot{W}_s + \sum_{i=1}^n F_{i0} H_{i0} - \sum_{i=1}^n F_i H_i = \frac{d\hat{E}_{sys}}{dt}$$

$$X_{EB} = \frac{\left(\frac{UA}{F_{A0}} (T - T_a) \right) + \sum \Theta_i C_{p_i} (T - T_{i0})}{-\Delta H_{Rx}}$$

$$X_{EB} = \frac{\sum \Theta_i C_{p_i} (T - T_0)}{-\Delta H_{Rx}}$$

$$T = T_0 + \frac{(-\Delta H_{Rx})X}{\sum \Theta_i C_{p_i}}$$

Multiple

$$\frac{dT}{dV} = \frac{Ua(T_a - T) + \sum r_{ij} \Delta H_{R,ij}}{\sum F_i C_{p_i}}$$

PBR

$$\frac{dT}{dW} = \frac{\frac{Ua}{\rho_B} (T_a - T) + r'_A \Delta H_{Rx}(T)}{\sum F_i C_{p_i}}$$

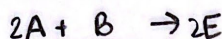
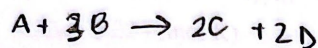
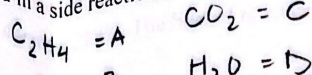
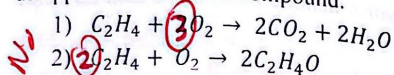
$$\frac{dT}{dW} = \frac{\frac{Ua}{F_{A0}} (T_a - T) + r'_A \Delta H_{Rx}(T)}{F_{A0} (\sum \Theta_i C_{p_i} + \Delta C_p X)}$$

CSTR

$$\frac{dT}{dV} = \frac{Ua(T_a - T) + r_A \Delta H_{Rx}(T)}{F_{A0} (\sum \Theta_i C_{p_i} + \Delta C_p X)}$$

$$\frac{dT}{dV} = \frac{Ua(T_a - T) + r_A \Delta H_{Rx}(T)}{\sum F_i C_{p_i}}$$

Problem 1: (30 pts). The production of ethylene oxide occurs from the reaction of ethylene and oxygen; however, carbon dioxide and water is produced in a side reaction as shown below. Provide net rates of disappearance for each compound.



1) $\frac{-r_A}{-1} = \frac{-r_B}{-3} = \frac{-r_C}{2} = \frac{-r_D}{2}$

$\frac{-r_A}{-2} = \frac{-r_B}{-1} = \frac{-r_E}{2}$

$\frac{-r_A}{-2} = \frac{-r_B}{-1} \Rightarrow r_B = \frac{1}{2}(-r_A)$

$\frac{-r_A}{-2} = \frac{-r_E}{2} \Rightarrow r_E = -1(-r_A)$

$\frac{-r_A}{-1} = \frac{-r_B}{-3} \Rightarrow -r_B = 3(-r_A)$

$\frac{-r_A}{-1} = \frac{-r_C}{2} \Rightarrow -r_C = -2(-r_A)$

$\frac{-r_A}{-1} = \frac{-r_D}{2} \Rightarrow -r_D = -2(-r_A)$

$-r_{A1} = kC_A C_B^3$

$-r_{A2} = kC_A^2 C_B$

NET RATES

$-r_{A(NEI)} = -r_{A1} + -r_{A2}$

$-r_{A(NEI)} = kC_A C_B^3 + kC_A^2 C_B$

$-r_{B, NET} = 3(-r_{A1}) + \frac{1}{2}(-r_{A2})$

$-r_{B, NET} = 3[kC_A C_B^3] + \frac{1}{2}[kC_A^2 C_B]$

$-r_{C, NET} = -2(-r_{A1}) + r_{A2}$

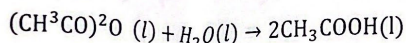
$-r_{C, NET} = -2kC_A C_B^3 + kC_A^2 C_B$

$-r_{D, NET} = -2(-r_{A1}) + r_{A2}$

$-r_{D, NET} = -2kC_A C_B^3 + kC_A^2 C_B$

$-r_{E, NET} = -1(-r_{A1}) + -1(-r_{A2})$

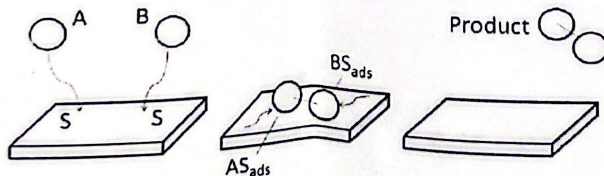
Problem #2: 15 pts Acetic anhydride reacts violently with water to make acetic acid; therefore, the reaction must be controlled.



- What type of reaction is occurring? hydration
- Is this reaction homogeneous or heterogeneous? (Simply circle your answer).
- Is this reaction endothermic or exothermic? (Simply circle your answer).

Problem #3: (15 pts) Answer the following set of questions.

- Runaway reactions are caused by which of the following types of reactions?
 a. Isothermal b. Endothermic c. Exothermic d. Adiabatic
- For exothermic reactions, what does a negative value of heat of reaction mean?
 a. Isothermal b. Endothermic c. Exothermic d. Adiabatic
- The following image refers to the Langmuir-Hinshelwood mechanism.



$$C_{A0} = F_{A0} v_0 \Rightarrow 1.5 \frac{\text{kmol}}{\text{m}^3} \times 0.002 \frac{\text{m}^3}{\text{s}} = 0.003$$

Problem #5: 35 pts A second order, liquid phase reaction $A + B \rightarrow C$ occurs in a jacketed CSTR. The reaction is assumed as elementary. The feed contains 1.5 kmol/m^3 of A and 1.0 kmol/m^3 of B with an initial volumetric flow rate of $0.002 \text{ m}^3/\text{s}$. A coolant is used at a constant 283 K . The heat of reaction is $-6.15 \frac{\text{kJ}}{\text{kmol of A}}$. $\times \frac{1000 \text{ J}}{1 \text{ kJ}} \times \frac{1 \text{ kmol}}{1000 \text{ mol}}$

Additional information:

$$X = 0.85;$$

$$U = 2.0 \text{ kJ/m}^2 \cdot \text{s} \cdot \text{K};$$

$$C_{PA} = 30 \text{ J/(mol} \cdot \text{K)};$$

$$C_{PB} = 18 \text{ J/(mol} \cdot \text{K)};$$

$$C_{PC} = 22 \text{ J/(mol} \cdot \text{K)}$$

$$k = 0.01 \frac{\text{m}^3}{\text{kmol} \cdot \text{s}}$$

$$v_0 = 0.002 \text{ m}^3/\text{s}$$

$$F_{A0} = (1.5 + 1) = 2.5 \frac{\text{kmol}}{\text{m}^3}$$

- a. Determine the reactor volume of the CSTR.

$$r_A = k C_A^2$$

$$V_{\text{CSTR}} = \frac{F_{A0} X}{-r_A} \Rightarrow \frac{1.5 \frac{\text{kmol}}{\text{m}^3} (0.85)}{(0.01 \frac{\text{m}^3}{\text{kmol} \cdot \text{s}}) (0.003)^2}$$

$$V_{\text{CSTR}} = 7.9 \times 10^{-6} \frac{\text{m}^3}{\text{s}}$$

$$V_{\text{CSTR}} = F_{A0} (k) (1-X)^2$$

$$V_{\text{CSTR}} = (1.5 \frac{\text{kmol}}{\text{m}^3}) (0.01 \frac{\text{m}^3}{\text{kmol} \cdot \text{s}}) (1-0.85)^2$$

- b. Calculate the heat transfer area necessary for a reactor temperature of 300 K ?

$$\frac{dT}{dV} = \frac{U_a (T_a - T) + r_A \Delta H_{rx} (T)}{F_{A0} (\sum \theta_i C_{pi} + \Delta C_p X)}$$

$$T_a = 283 \text{ K}$$

$$T = 300 \text{ K}$$

$$0.00225 \text{ m}^3$$

$$\Delta C_p X = U_a (T_a - T) + r_A \Delta H_{rx} T$$

$$(30 \frac{\text{J}}{\text{mol} \cdot \text{K}} - 18 \frac{\text{J}}{\text{mol} \cdot \text{K}}) (0.85) = (2000 \frac{\text{J}}{\text{mol} \cdot \text{s}}) a (283 \text{ K} - 300 \text{ K}) + (10 \frac{\text{m}^3}{\text{mol} \cdot \text{s}}) (-6.15 \frac{\text{J}}{\text{mol}})$$

- c. How much heat is being removed during the reaction?

$$X_{EB} = \left(\frac{U A}{F_{A0}} \right) (T - T_a)$$

$$12 \frac{\text{J}}{\text{mol} \cdot \text{K}} \times 0.85 = -34000_a +$$

Problem #6: 30 pts

The following first order, elementary reaction takes place in a catalytic membrane reactor (CMR):

Component B diffuses through the membrane and component C is the desired product. Unfortunately, component A also diffuses through the membrane.
 $A \leftrightarrow B + 2C$

- a. Provide mole balance equations for each compound in terms of flow rate.

$$\frac{dF_A}{dV} = (r_A - R_A), \quad \frac{dF_B}{dV} = (r_B - R_B)$$

- *b. A rate of disappearance for component A.

$$(-r_A) = k_1 C_A - k_{-1} C_B C_C^2$$

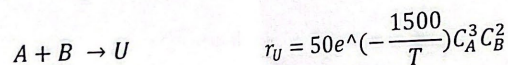
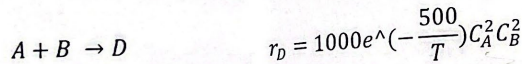
$$\frac{dF_C}{dV} = r_C$$

- *c. Transport equations (kinetics) for the components that diffuse through the membrane.

$$R_A = k_A C_i$$

$$R_B = k_B C_i$$

Problem #7: 25 pts Consider the following parallel reactions where the desired product is achieved in the first reaction.



- a. Derive and simplify an expression for the selectivity of D to U.

$$S_{D/U} = \frac{r_D}{r_U} = \frac{1000 e^{(-\frac{500}{T})} C_A^2 C_B^2}{50 e^{(-\frac{1500}{T})} C_A^3 C_B^2} \rightarrow \frac{20 e^{(-\frac{500}{T})} C_A^2 C_B^2}{e^{(-\frac{1500}{T})} C_A^3 C_B^2}$$

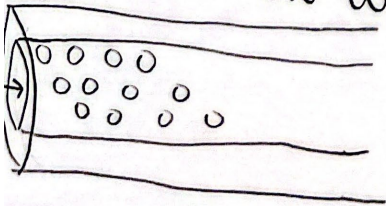
Simplify - 4

- b. To maximize the production of the desired products, what setting is required for the temperature?

To maximize the desired products the temperature should be higher. - 6

- c. What type of reactor should we use? Sketch an image to support your suggestion.

A membrane reactor should be used - 8
With a high concentration of B and a low concentration of A. (Case 2)



**CHEG 3306-02: KINETICS AND REACTOR DESIGN
SPRING 2022 SEMESTER**

Title of Assignment: REACTOR CHARACTERISTIC QUIZ

TOPICS COVERED IN REACTOR CHARACTERISTIC QUIZ

REACTOR CHARACTERISTIC QUIZ covered the following topics:

1. Reactor advantages/disadvantages
2. Phases in each reactor
3. Optimum operating conditions

ABOVE AVERAGE

Score for this quiz: **25** out of 25

Submitted Jan 31 at 4:49pm

This attempt took 8 minutes.

Question 1

Question Score / 3 pts

Which reactor is primarily operated in the gas phase?

Correct!



PFR



BATCH



PBR



CSTR

Question 2

Question Score / 3 pts

What type of reactor is used to minimize unwanted side reactions?

Correct!



Semi-batch



Batch



FBR



CSTR

Question 3

Question Score / 3 pts

Which of the following reactors has concentration changes down the length of the reactor?



Semi-batch

☐

Batch

Correct!

☒

PFR

☐

CSTR

Question 4

Question Score / 3 pts

Which type of reactor is used in the pharmaceutical industry?

☐

PBR

Correct!

☒

Batch

☐

Semi-batch

☐

CSTR

Question 5

Question Score / 3 pts

Which of the following is NOT an advantage of using a CSTR?

☐

Low labor operating cost

☐

Easy to clean

☐

Good temperature control

Correct!

☒

High conversion per unit volume



No answer text provided.

Question 6

Question Score / 2 pts

A CSTR is a reactor with a continuous flow of reactants and products that assumes a uniform composition throughout the reactor.

Correct!



True



False

Question 7

Question Score / 2 pts

A packed bed reactor uses catalysts. The catalyst may cause channeling in the reactor.

Correct!



True



False

Question 8

Question Score / 2 pts

The phases in a PBR include liquid and solid catalyst.



True

Correct!



False

Question 9

Question Score / 2 pts

For a PFR, there is no change in concentration down the length of the reactor.



True

Correct!



False

Question 10

Question Score / 2 pts

A semi-batch reactor is a combination of a CSTR and a PFR.



True

Correct!



False

Final Score: 25 out of 25

AVERAGE

Score for this quiz: **22** out of 25
Submitted Jan 31 at 11:36pm
This attempt took 7 minutes.

Question 1

Question Score / 3 pts

Which of the following is NOT a disadvantage of a fluidized bed reactor?

☐

Large pressure drops

Correct!

☒

Uneven particle mixing

☐

Large reactor volume required

☐

Vessel erosion

Question 2

Question Score / 3 pts

Which type of reactor is also known as a fixed bed reactor?

You Answered

☒

FBR

☐

CSTR

☐

PFR

Correct Answer

☐

PBR

Question 3

Question Score / 3 pts

Which of the following reactors does not have good temperature control?

Correct!

☒

PFR



CSTR



Semi-batch



Fluidized Bed

Question 4

Question Score / 3 pts

What type of reactor is used to minimize unwanted side reactions?



FBR



CSTR



Batch

Correct!



Semi-batch

Question 5

Question Score / 3 pts

Which type of reactor is used in the pharmaceutical industry?



Semi-batch



PBR

Correct!



Batch



CSTR

Question 6

Question Score / 2 pts

The phases in a PBR include liquid and solid catalyst.

☐

True

Correct!

☒

False

Question 7

Question Score / 2 pts

A CSTR has poor temperature control.

☐

True

Correct!

☒

False

Question 8

Question Score / 2 pts

A CSTR runs at unsteady state.

☐

True

Correct!

☒

False

Question 9

Question Score / 2 pts

A CSTR is a reactor with a continuous flow of reactants and products that assumes a uniform composition throughout the reactor.

Correct!

☒

True

☐

False

Question 10

Question Score / 2 pts

The catalyst in a PBR undergo fluidization.



True

Correct!



False

Final Score: 22 out of 25

BELOW AVERAGE

Score for this quiz: **19** out of 25
Submitted Jan 31 at 10:22pm
This attempt took 19 minutes.

Question 1

Question Score / 3 pts

Which of the following is NOT a disadvantage of using a PFR?

Correct!



High operating cost



Undesired thermal gradients may exist



Poor temperature control



Shutdown and cleaning may be expensive

Question 2

Question Score / 3 pts

Which of the following is an advantage of using a BATCH reactor?

Correct!



High conversion per unit volume for one pass



Consistent product quality



Low operating cost



Limited flexibility in usage

Question 3

Question Score / 3 pts

Which of the following reactors has concentration changes down the length of the reactor?

Correct!



PFR

☐

Batch

☐

CSTR

☐

Semi-batch

Question 4

Question Score / 3 pts

Which type of reactor is also known as a fixed bed reactor?

Correct Answer

☐

PBR

☐

PFR

You Answered

☒

FBR

☐

CSTR

Question 5

Question Score / 3 pts

Which reactor is primarily operated in the gas phase?

Correct Answer

☐

PFR

☐

CSTR

☐

BATCH

You Answered



PBR

Question 6

Question Score / 2 pts

The catalyst in a PBR undergo fluidization.



True

Correct!



False

Question 7

Question Score / 2 pts

A packed bed reactor uses catalysts. The catalyst may cause channeling in the reactor.

Correct!



True



False

Question 8

Question Score / 2 pts

A CSTR runs at unsteady state.



True

Correct!



False

Question 9

Question Score / 2 pts

A BATCH reactor undergoes continuous operation.



True

Correct!



False

Question 10

Question Score / 2 pts

Both PBR and FBR use catalyst.

Correct!



True



False

Final Score: 19 out of 25