BSEN 445/845: Bioprocess Engineering

General Information:

Class Time/Credits:	12:30-1:45 pm; Tuesday and Thursday (3 credit hours)
Location:	149 Chase Hall
Instructor:	Hyun-Seob Song, 212 Chase Hall, 402-472-1036 hsong5@unl.edu
Office Hours:	By appointment

Catalog Description:

Engineering topics related to processing of biological materials into valuable products. The course covers enzyme kinetics, microbial kinetics, application of enzymes in industrial processes, bioreactor design, equipment scale-up, gas transfer in reactors and bioseparations.

Prerequisites:

- Undergraduate students: BSEN 344 or CHME 333
- Graduate students: Knowledge on transport phenomena

Learning Outcomes:

For undergraduate students

1. Understand microbial growth and enzymatic kinetics and apply the models for the analysis of bioreactors (ABET Outcome 1).
2. Utilize material balances to evaluate cell growth and substrate/product utilization in bioreactors (ABET Outcome 1).
3. Design bioreactors to achieve desired results (i.e., specified cell concentration, production rates).
4. Understand and apply scale-up and mixing rules for designing bioreactors.
5. Learn how to work as a team in conducting a term project where students analyze and interpret the given data, develop conclusions, and apply conclusions for bioprocess operation, development, design, and scale-up (ABET Outcomes 5 & 6).
6. Build an ability to effectively present the outcomes of the term project to the entire group (ABET Outcome 3).

Graduate students share the same learning outcomes above, but conduct and present term projects *individually*.

Required materials: None. The course materials are developed based on the following multiple references:

- Bioprocess Engineering: Basic Concepts, 3rd Edition, Michael Shuler, Fikret Kargi, and Matthew DeLisa, Prentice Hall, 2017
- Bioprocess Engineering: Kinetics, Sustainability, and Reactor Design, 3rd Edition, Shijie Liu, 2020
- Cell Culture Bioprocess Engineering, 2nd Edition, Wei-Shou Hu, CRC Press, 2020

- Cybernetic Modeling for Bioreaction Engineering, Doraiswami Ramkrishna and Hyun-Seob Song, Cambridge University Press, 2018
- Chemical Engineering Design and Analysis: An Introduction, 2nd Edition, Michael Duncan and Jeffrey Reimer, Cambridge University Press, 2019
- Scale-up in Chemical Engineering, 2nd Edition, Zlokarnik, Wiley-VCH, 2006
- Handbook for a Short Course on Scale-up & Mixing (SCOSUM), LG Chem, 2005

Communication with Instructor: Emails and/or Canvas will be used. All email communication will be to your UNL email address.

Policies:

Attendance. No policy.

Department academic dishonesty and grade appeals policy which can be found at:

http://engineering.unl.edu/downloads/files/AcademicDishonesty_Appeals_1.pdf

University-wide course policies and resources:

https://executivevc.unl.edu/academic-excellence/teaching-resources/course-policies

Instructional Continuity Plan: If in-person classes are cancelled, you will be notified of the instructional continuity plan for this class by Canvas and/or email.

Grading

Homework: Homework assignments will be notified on Canvas. You may post a picture of your homework, a PDF, MS Word document, and/or MS Excel spreadsheet as appropriate. No late work will be accepted.

Exams: There will be one written exam during the semester. Exam problems are based on problems assigned for homework. Grading of exam questions is based on using the correct methodology to solve problems and obtaining the correct answer. Partial credit is awarded for correctly solving parts of each problem. NO early, late, or make-up exams will be given unless approved by the instructor. A missed exam will be counted as a score of zero.

Term project: *Undergraduate students* will work in small groups (composed of two or three students) to conduct term projects; *graduate students* will perform term projects individually.

- Step 1: Identify appropriate kinetics of biochemical reactions using in silico kinetic data generated by the instructor.
- Step 2: Incorporate the kinetics identified in Step 1 into the mathematical models of small-scale batch and continuous cultures (provided from the instructor) and evaluate the reactor performance.

- Step 3: Determine geometrical and operating parameters for larger-scale batch and continuous cultures by applying appropriate scale-up rules learned from the class.
- Step 4: Prepare a 15-minute oral presentation based on the results obtained. The rubric the instructor uses to grade the presentation will be given to you several weeks prior to the presentation date. More details will be provided during the semester.

Quizzes. None.

Grading scheme:

For both undergraduate and graduate students:

Exam	30 %
Homework	30 %
Project	40 %

The following letter grades are guaranteed if you have the following percentage of points:

A+	> 97%	A	93-97%	A-	90-93%
B+	87-90%	B	83-87%	B-	80-83%
C+	77-80%	C	73-77%	C-	70-73%
D+	67-70%	D	63-67%	D-	60-63%
F	<60%				

The instructor may lower these percentages, but they will not raise them.

Tentative Schedule

Week	Date	Subjects covered / activities / exams	
1	8/22 (T)	1.1 Course overview	
	8/24 (R)	1.2 Enzyme kinetics: basics	
2	8/29 (T)	1.3 Enzyme kinetics: inhibition	HW1
	8/31 (R)	1.4 Enzyme kinetics: pH and temperature	
3	9/5 (T)	1.5 Enzyme kinetics: immobilized enzymes	HW2
	9/7 (R)	1.6 Cell growth: basics	
4	9/12 (T)	1.7 Cell growth: stoichiometry 1	
	9/14 (R)	1.8 Cell growth: stoichiometry 2	
5	9/19 (T)	1.9 Cell growth: diauxie and cybernetic modeling	HW3
	9/21 (R)	1.10 Cell growth: inactivation	
6	9/26 (T)	2.1 Batch and continuous cultures	
	9/28 (R)	2.2 Chemostat with recycle	HW4
7	10/3 (T)	2.3 Multistage chemostat systems	
	10/5 (R)	2.4 Packed-bed reactors and immobilized cells	HW5
8	10/10 (T)	2.5 Residence time distributions	
	10/12 (R)	2.6 Oxygen and heat transfer	HW6
*	10/17 (T)	NO CLASS (Fall Break)	

	10/19 (R)	Summary of Part 2	
9	10/24 (T)	**Exam (Parts 1 & 2)**	
	10/26 (R)	3.1 Dimensional analysis	
10	10/31 (T)	3.2 Pi Theorem, Pi-sets, and Pi-space	HW7
	11/2 (R)	3.3 Scale-up rules	
11	11/7 (T)	3.4 Scale-up exercise (1)	AIChE (11/5-10)
	11/9 (R)	3.5 Scale-up exercise (2)	AIChE (11/5-10)
12	11/14 (T)	3.6 Mixing in stirred vessels	
	11/16 (R)	3.7 Mixing in pipes	
13	11/21 (T)	Summary of Part 3	
	11/23 (R)	NO CLASS (Thanksgiving)	
14	11/28 (T)	Bioprocess engineering in pharmaceutical industry (1) – online lecture by Dr. Nandkishor Nere from AbbVie	
	11/30 (R)	Bioprocess engineering in pharmaceutical industry (2) – online lecture by Dr. Nandkishor Nere from AbbVie	HW8
15	12/5 (T)	**Project presentation (1)**	
	12/7 (R)	**Project presentation (2)**	
*	12/11 - 22	Grading	

Scope of homework:

- HW1: Derive enzymatic kinetics including inhibition; determine kinetic parameters via graphical analyses of data
- HW2: Analyze the impact of pH and temperature into kinetics; analyze the impacts of mass transfer limitations in immobilized enzymes
- HW3: Determine reaction stoichiometries from elemental mass and redox balances; kinetic and cybernetic models; determine microbial inactivation parameters
- HW4: Determine performance indices using batch and continuous culture equations; quantify the impacts of recycle in continuous cultures
- HW5: Quantify the impacts of the number of stages on chemostat performance; analyze the impacts of mass transfer limitations in packed-bed reactors
- HW6: Calculate residence time distributions from ideal and non-ideal reactors; analyze the impacts of mass and heat transfer
- HW7: Generate Pi-sets using dimensional analysis; show scale-invariance of Pi-space
- HW8: Provide a summary of what you learned from guest lectures