ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

New Orleans JAZZED about Engineering Education

Paper ID #17462

Teaching Chemical Engineering Courses in a Biomolecular Engineering Program

Prof. Faisal Shaikh, Milwaukee School of Engineering

Dr. Faisal Shaikh joined MSOE about 6 years ago in a unique interdisciplinary engineering program called BioMolecular engineering. The program was a combination of molecular biology and chemical engineering and is unique in the nation. Being the lone chemical engineering faculty member in the program, he was tasked of developing a significant number of the core chemical engineering courses, albeit with a focus on biology. The program recently successfully went through the initial ABET accreditation. He is also a champion of industry-academia partnerships in senior design projects and has been instrumental in bringing full industry sponsorship to the majority of the senior design projects in the program he teaches in.

Prof. Serdar Ozturk, MSOE

Dr.Serdar Ozturk is an assistant professor in Biomolecular Engineering program at Milwaukee School of Engineering (MSOE). This unique program is a hybrid program of molecular biology and chemical engineering and successfully went through the initial ABET accreditation. As a chemical engineer in the program, he developed and modified many core chemical engineering courses (Reactor Design, Thermodynamics I and II, etc.), albeit with a focus on biology. He constantly seeks opportunities to introduce our BioE program to the industry by creating collaborations through senior design and research projects.

Teaching Chemical Engineering courses in a BioMolecular Engineering program

A new interdisciplinary engineering program-BioMolecular Engineering- which is substantially different than “Chemical and Biomolecular Engineering” and similar programs offered in other universities, was launched in the Midwest in 2009 (ABET accreditation under the Chemical Engineering criteria, effective since 2012), that combined the curriculum of chemical engineering with molecular biology. There is no Chemical Engineering program currently offered at our university and this is a stand-alone Engineering program in our department.

This posed significant challenges in developing the chemical engineering courses with a ‘bio-focus’ so that they would complement the bio-skillset provided in the new curriculum. The chemical engineering courses offered in the program were Reactor Design, Thermodynamics, Transport Phenomena, Unit Operations and Process Control. The authors developed a set of novel *modified* courses geared towards bioprocessing. All of these courses were designed with chemical engineering fundamentals applied primarily to bioprocessing.

In this paper, the authors, who are both trained chemical engineers, share information about these courses, associated outcomes, topics and important additions and modifications that they have done on traditional core chemical engineering course formats. The information on these courses is sequentially provided in the next section.

1. Kinetics and Bioreactor Design Course:

1.1 Course description

This course is offered in Spring quarter of Junior year. It addresses the selection of the optimal configuration and size of production scale bioreactors for specific applications. The design of fermentation reactors and cell culture type bioreactors and their applications are discussed. Course topics include: reactor types, reaction kinetics (batch reactor, semi-continuous reactor, continuous reactors (CSTR, PFR, PBR), Chemostats), and fundamental reaction parameters, substrate consumption kinetics, production kinetics for bioreactions, mass and energy balances on the reactors. Course material is applied to practical reactor selection, sizing, scale-up and operation.

1.2 Course outcomes

Upon successful completion of this course, the student will:

1. derive and apply macroscopic mole and energy balances to size reactors.
2. analyze lab data to ascertain the kinetics of a reaction and scale-up design of a bioreactor from lab data.
3. distinguish between various types and arrangements of reactors and understand their operation.
4. design or select a bioreactor for a specific purpose.
5. use a mathematical tool to solve systems of equations.

1.3 Modifications done to focus on bioprocessing

The list of topics added to the course besides traditional topics covered in similar courses offered at other institutes are listed in Table 1 below.

Table 1. List of the additional topics included in the Kinetics and Bioreactor design course

Chapters	**Additional Topics**
Enzymes and Enzymatic Reactions	It is required to learn the fundamentals of structure of enzymes, enzyme-substrate interactions, inhibition mechanisms, rate laws involving enzymes (biocatalysts), for example the rate law for urea decomposition
Cell Growth	Growth kinetics, the importance of phases of cell growth, for example antibiotic production in the stationary phase
Multiple reactions	Pharmacokinetics examples
Types and structure of reactors	Batch, continuous-stirred, fed batch reactor types, also introduction of airlift reactors and perfusion systems,
Batch Reactors	Yield definitions, rate laws written for substrate utilization (consumption by cells, consumption to form products, consumption for maintenance), death of cells, products,
Chemostats /CSTR Mass Balances	Mass balances (for microorganisms, substrates, and products), dilution rate, wash-out, mass transfer of oxygen in aerobic fermentation

This course included more emphasis on stirred tank reactors with unsteady state batch operation due to their applications in bioprocessing. Bioprocessing projects from real world applications (such as from biofuel, solar thermal biochar gasification, and biopharmaceutical industry) are assigned to students.

2. Thermodynamics II Course

2.1 Course description

This course is offered in Fall quarter of Junior year. It surveys the use and application of classical and statistical thermodynamics to chemical, biochemical and biomolecular systems. It covers the application of the First and Second Laws of thermodynamics to living systems, solution thermodynamics, free energy and phase and reaction equilibriums are used to examine biomolecular reactions, energy conversion, binding, molecular thermodynamics (including an introduction to statistical thermodynamics). Examples and applications are drawn from chemical and biomolecular engineering fields.

2.2 Coures outcomes

Upon successful completion of this course, the student will:

1. understand solution thermodynamics, chemical and bio-reaction equilibria and phase equilibria and be able to use thermodynamic properties of fluids to solve problems.

2. gain a fundamental understanding of the thermodynamics principles and molecular thermodynamics and their relevance in the biomolecular world.
3. develop a fundamental understanding of concepts such as: entropy, enthalpy, free energy, internal energy, the conservation of energy, etc. and their relevance in biomolecular engineering.
4. have the ability to identify problems, formulate solutions and solve using thermodynamic principles.
5. understand fundamental equations of state applied to intramolecular and intermolecular interactions.
6. be able to apply fundamental thermodynamic relationships at the molecular level for such events as molecular cooperativity and binding.

2.3 Modifications done to focus on bioprocessing

The list of topics added to the course besides traditional topics covered in similar courses offered at other institutes are listed in Table 2 below.

Table 2. List of additional topics included in the Thermodynamics II course

Chapters	**Additional Topics**
Bioenergetics: Endergonic and exergonic processes	Biochemical reactions, Standard states in Biochemistry, Coupled reactions, Gibbs free energy change calculations,
Biological membranes and osmotic pressure	Determination of molecular weight of biomolecules in solutions
Molecular Thermodynamics	Probability, Multiplicity, Entropy and Boltzmann distribution
Binding	Multi-site and cooperative ligand binding, Bio & Nano machines

3. Transport Phenomena II Course

3.1 Course description

This course is offered in Winter quarter of Junior year. It covers concepts, procedures and techniques related to the application of heat and mass transfer principles to the process of heat exchange, evaporation, condensation, boiling and drying operations in biological and biomolecular systems. Integral and differential transport equations are applied to the solution of heat and mass transfer problems of interest to biomolecular engineers. The analysis and solution of mass and heat transfer problems involving conduction, convection, and radiation are discussed. Analogies between heat, mass and momentum problems and mass transfer in biological systems are the focus.

3.2 Course outcomes

Upon successful completion of this course, the student will:

1. gain a fundamental understanding of the modes of heat and mass transfer.
2. gain the ability to use the governing equations and boundary conditions of heat transfer and mass transfer and understand their relevance in the biological world.
3. gain a fundamental understanding of conductive and convection heat transfer and how it applies to biomolecular problems.
4. develop a fundamental understanding of concepts such as: thermal conductivity, thermal diffusivity, convective and radiative heat transfer, diffusion, dispersion, and convective mass transfer, etc. and their relevance in biomolecular engineering.
5. have the ability to identify problems, formulate solutions and solve using mass and heat transfer principles.
6. be able to apply fundamental heat and mass transfer relationships to processes such as heat exchange, evaporation, condensation, boiling and drying operations in biological and biomolecular systems.

3.3 Modifications done to focus on bioprocessing

The list of topics added to the course besides traditional topics covered in similar courses offered at other institutes are listed in Table 3 below.

Table 3. List of the additional topics included in the Transport phenomena II course.

	Chapters	**Additional Topics**
Heat Transfer	Freezing and Thawing	Freezing process in cellular tissues, Time for freezing calculations for different biomaterials, freezing point depression, Cryopreservation,
	Conduction and Convection	Thermoregulation, food sterilization
	Radiation and Photosynthesis	Radiation emitted by a body/human/plants, Radiation exchange between organism and its surroundings
Mass Transfer	Diffusion	Diffusional limitations in immobilized cell systems, Photosynthesis and transport of water vapor and CO_2 in a leaf, Oxygen diffusion in tissues, factors affecting oxygen transfer in fermenters, drug delivery

4. Unit Operations course

4.1 Course description

This course applies the principles of phase equilibrium, transport processes and chemical kinetics to the design and characterization of batch and continuous separation processes. Graphical and rigorous numerical techniques are used in the design and scale-up of associated process equipment. The general procedures applicable to various processes are emphasized. Sample problems are drawn from the chemical, food and biochemical processing industries. Laboratory topics include techniques related to common production scale operations, which include filtration, flocculation, extraction, centrifugation and chromatography.

4.2 Course outcomes

Upon successful completion of this course, the student will be able to:

1. Apply the principles of transport processes, phase equilibrium and chemical kinetics to design and characterize batch and continuous separation unit processes
2. Describe the operation of various unit processes
3. Design and scale-up the equipment for unit processes
4. Perform biomolecular engineering experimentation

4.3 Laboratory Topics

1. Flocculation
2. Dead end filtration
3. Tangential Flow Filtration
4. Liquid-Liquid Extraction, supercritical CO_2 extraction
5. Chromatography
6. Centrifugation
7. Freeze drying

4.4 Modifications done to focus on bioprocessing

The list of topics added to the course besides traditional topics covered in similar courses in other institutes are listed in table 4 below.

Table 4. List of the additional topics included in the Unit Operations course.

Chapters	**Additional topics**
Sedimentation	Flocculation
Filtration	Tangential flow filtration
Extraction	Supercritical CO_2 extraction
Drying	Freeze drying

The Unit Operations course (named as Unit Operations-Production Scale Bioseparations) did not focus as much on distillation (being a heat intensive process) in detail. While distillation is a workhorse for separations in chemical processing industry, other techniques (e.g., supercritical CO_2 extraction, freeze drying, chromatography etc.) find more importance in bioseparations. The exception to this is the biofuel industry or any bioproduct that is not heat sensitive. The lab experiments for this course follow the same logic and are modified accordingly.

5. Bio-Process Control

5.1 Course Description

The course provides a comprehensive training on industrial bio process control. Process control hardware and troubleshooting, dynamic modeling, controller tuning and control of processes is covered in detail. P, PI and PID controllers are analyzed along with advanced control strategies. The course also provides an introduction to the design of complex, multistep industrial scale biomolecular processes.

5.2 Course Outcomes

Upon successful completion of this course, the student will be able to:

1. Identify common process instrumentation
2. Design and analyze a process control strategy for a process requirement
3. Choose an appropriate control strategy for a given process requirement
4. Tune PID controllers
5. Mathematically analyze control behavior of process control loops
6. Design and implement appropriate control strategies for a given process requirement
7. Synthesize the flowsheet/sequence of unit operations needed in a biomanufacturing process

5.3 Modifications done to focus on bioprocessing

The list of topics added to the course besides traditional topics covered in similar courses in other institutes are listed in table 5 below.

Table 5. List of the additional topics included in the Bio-Process Control course.

Chapters	**Additional topics**
Process hardware	Instrumentation common in bioprocessing, biosensors, valve sizing
Dynamic modeling	Focus on bioprocesses
Advanced topics	Non linear model predictive control, gain scheduling

Process control in Bioprocessing is complicated due to the non-linear nature of bioprocesses. We have introduced advanced process control strategies that are beneficial for the inherently non-linear bioprocesses. Additional topics like Model predictive control and Gain scheduling are introduced. Internal Model Control (IMC) tuning is a clever technique/topic but it assumes you have a model for the process (which is a little complicated for bioprocesses). Interestingly, a PID controller could be easily tuned by the time it would take you to derive a model of the process. BODE plots relate to steady state processes and are thus not as relevant in bioprocessing and not discussed in detail.

6. Conclusion

This paper has provided a summary of the modifications that would be needed in traditional core chemical engineering courses that are part of a hybrid ‘bio’ focused engineering program. The chemical engineering courses offered in the program were Reactor Design, Thermodynamics, Transport Phenomena, Unit Operations and Process Control. In general, the modifications to the courses involved addition of topics relevant to bioprocessing eg. in the course on unit operations, there is more emphasis on separation techniques that are less shear and heat intensive and consequently, less emphasis on techniques like distillation due to their inapplicability for most bioproducts. Time needed for the additional topics is obtained by decreasing the time spent in some other traditional chemical engineering topics, that are less relevant for bioprocessing. This paper serves as a useful reference for any faculty, with a chemical engineering background, who may teach similar courses in such hybrid programs.