Incorporating Biotechnology in the Chemical Engineering Curriculum

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Abstract:

The projected growth of the biotechnology industry in the coming decades warrants changes in traditional chemical engineering curricula. To meet this new challenge, Manhattan College has implemented curriculum changes that aim at preparing graduates to meet the demands of the food and pharmaceutical industry with a basic knowledge of biology and biochemistry for entry-level chemical engineers. Sophomores are now required to take one of two biology courses (Genetics or Molecular Biology) with biology majors. As seniors, students can elect to take another biology course (Immunology, Pharmacology, or Physiology) or a biochemistry course as their advanced science elective. Other opportunities are available to them such as enrolling in Bioreaction Engineering, Bioseparation Engineering, Membrane Process Technology, Industrial Microbiology and/or Biological Treatment Processes as senior engineering elective courses. Research opportunities in the areas of biochemical engineering are also available through collaborations with the Biology Department at Manhattan College and the Earth Engineering Center at Columbia University.

Introduction:

From its inception in 1958, the Chemical Engineering Department at Manhattan College has sought feedback from its Advisory Board and employers to improve its programs at both the undergraduate and graduate levels. In the 1960s the local manufacturing industries were mostly chemical and petrochemical including: Exxon Research & Engineering (NJ), Mobil Research & Development (NJ), Texaco (NY), Universal Oil Products (NY), Union Carbide (NY, CT), and American Cyanamid (NY, NJ & CT). In recent years, many of those industries have closed their Northeast sites causing a shift in the local job market towards the food and pharmaceutical industries. This has led to the addition of representatives from Pfizer (NY, CT), Merck (NJ), Nestle (NJ), and Kraft (NY, NJ) to the Advisory Board. Future additions will include members from other local food, pharmaceutical, and biotechnology companies that hire our graduates including Bristol Myers-Squibb, Wyeth-Ayerst Laboratories, OSI Pharmaceuticals, PepsiCo, and Seagrams.

In an effort to continuously meet the needs of our constituencies (employers and students), and encouraged by the reported 11% increase in employment in the pharmaceutical sector between 1994 and 1997 in New York State[1], plus the doubling in size of the biotechnology industry in the U.S. as a whole between 1993 and 1999[2], we have revised the chemical engineering curriculum. This paper presents those revisions at both the undergraduate and graduate levels, including biology and biochemical engineering components, laboratory applications and research projects.

The Revised Curriculum

The Chemical Engineering Department has offered an elective course in biochemical engineering since the early 1980s. In the mid 1980s, a Biochemical Engineering Laboratory was built by the College, furnished by Duracell Corp., and equipped with grants from NSF, NIH and the New York State Science and Technology Foundation plus donations from industry. The laboratory includes equipment for fermentation and downstream separations, which is used for several experiments in the bio-oriented chemical engineering elective courses. It also provides research opportunities for the undergraduate and full-time graduate students who are interested in this area. Unfortunately, the bio-oriented electives are not offered every year and research projects are limited by availability of grants and faculty advisors. In order to give all of the students an exposure to biotechnology, required undergraduate courses in the biological sciences were added and a commitment was made to the students that at least one bio-oriented chemical engineering elective would be offered every year. The Biology Department currently offers a biology for engineers course tailored to the environmental and civil engineering students, but this course did not satisfy our goals. The chemical engineering students take all of their chemistry courses with the chemistry and biochemistry majors; thus, it was decided that exposure to modern biology should be acquired in an interdisciplinary setting with the biology and biochemistry majors. It was also decided that a laboratory component was needed in both the science and engineering courses. Table 1 outlines the courses that have biotechnology focus.

Table 1. Courses with a Biotechnology Focus

Bachelor of Science Degree		**Master of Science Degree**	
Required Course in Chem. Eng.		*Elective Courses in Chem. Eng.*	
Genetics or Molecular Biology	3 cr.	Bioreaction Engineering	3 cr.
Elective Courses		Bioseparation Engineering	3 cr.
Advanced Science Elective	3 cr.	Membrane Process Technology	3 cr.
Bioreaction Engineering	3 cr.	Industrial Microbiology	3 cr.
Bioseparation Engineering	3 cr.	Biological Treatment Processes	3 cr.
Senior Honors Project	3-6 cr.	Graduate Research	3-6 cr.

Modern Biology Courses

Starting Fall 2002, all chemical engineering students will be required to take a biology course in their sophomore year. To allow for this change, the 6-credit sequence in Physical Chemistry was condensed to one 3-credit course after careful review of the topics covered in those courses as well as in the two required engineering thermodynamics courses. In the new curriculum, students have a choice between Genetics, which is open to all of the students and Molecular Biology, which is recommended for students who have biology advanced placement credits. Both courses include a laboratory component and a term paper on a relevant topic. The Genetics course comprises transmission genetics, also known as classical or Mendelian genetics, population/evolutionary genetics, and molecular level genetics. Laboratory experiments include: Tetrad analysis in Sordaria, Drosophila cross, probability and chi-square test, DNA fingerprinting using PCR, restriction mapping, and Ames test. The Molecular Biology course comprises the study of the structure, function, interrelationships of the cell's macromolecules, and protein synthesis. The laboratory is a large project that consists of the following experiments: cloning a partial cDNA for Protein X into expression plasmid pET5a, expression of Protein X, identification of the X EDNA by DNA sequencing, and characterization of Protein X.

Advanced Science Electives:

Seniors can choose an advanced science elective from Biochemistry, Immunology, Pharmacology, or Physiology. The Biochemistry course discusses the chemistry of biologically important amino acids, proteins, carbohydrates, lipids, vitamins and hormones as well as enzyme kinetics and catalysis, protein structure and function, coenzymes and the energetics of metabolism including glycolysis, the citric acid cycle, electron transport, and oxidative phosphorylation. Immunology discusses the properties of antigens and antibodies, and theories of antibody production, tolerance, transplantation immunity, autoimmunity, tumor immunology, immunochemistry, and clinical immunology. It represents one of the most interdisciplinary fields within Biology. Pharmacology discusses disease states and their treatment by pharmacological means with special emphasis on the descriptive influence of pathology on systemic function and the use of drugs to restore balance. The course covers major drug classes and prototype drugs, the use and therapeutic effects of drugs in specific disease states, possible adverse response to drug therapy and indicated intervention, and sources of information available to keep drug knowledge current. Physiology discusses dynamic aspects of the functioning of cells, organs, and systems in animals and plants, organized around the themes of energy, information, and homeostasis. Laboratory experiments include: enzyme kinetics, cell cycle kinetics, active transport in yeast, cytochrome oxidase, membrane liquids, and nerve conduction.

Biochemical Engineering Courses

Two biochemical engineering courses are offered in the form of combined senior/graduate electives: Bioreaction Engineering and Bioseparation Engineering. Additional courses are: Membrane Process Technology, Industrial Microbiology, and Biological Treatment Processes. Since chemical engineering students (undergraduate and graduate) learn their molecular biology, genetics, and biochemistry in courses taught by science professors, the biochemical engineering courses can focus on engineering aspects of biotechnology.

Bioreaction Engineering was last taught in Fall 2001 with registration of 18 students, four seniors plus fourteen graduate students, half of whom were working in industry. The textbook used is written by Shuler and Kargi[3] and topics included enzyme kinetics, microbial kinetics and stoichiometry, batch and continuous fermentation, determination of mass transfer coefficients from static and dynamic data, and calculation of mass transfer coefficients based on aeration and agitation. Material from Bailey and Ollis[4] and Treybal[5] was used for the unit on agitation and aeration in airlift and stirred fermentors. The students ran two experiments, Kinetics of Batch Fermentation and Oxygen Transfer in Bioreactors. The objective met with these experiments was, “to obtain hands-on experience with batch fermentors and associated equipment.” The data taken in the experiments parallel some of the homework problems from Shuler and Kargi.[3]

Even though the focus of the Bioreaction Engineering course was on engineering calculations and analysis of fermentation data, one of the goals was “to develop an enhanced awareness of current advances in biotechnology.” This goal was met with reports by the students and an introductory session by the professor that opened with the question, “What do the following things have in common? Doonesbury, President G.W. Bush, ’ER,’ and ’The Boys from Brazil’?” The answer was Biotechnology (which nobody got). Gary Trudeau’s cartoon

Doonesbury ran a series on stem cells the first week of the fall semester, and the President had just held a nationally-televised press conference about stem cells. There is an article from *Chemical and Engineering News*[6] that opens with a discussion of an episode from the television drama series "ER" where the patient demanded TPA (tissue plasminogen activator), a genetically engineered drug that is given to prevent abnormal blood clotting during heart attacks. The movie, "The Boys from Brazil," is based on the concept of evil scientists cloning babies from Hitler's genes. The students had heard about stem cells and human cloning but claimed to study all the time instead of watching old movies and "ER."

The students were required to select a current topic, give a 5 to10-minute PowerPoint presentation to the class on their topic, and submit a 5 to 10-page written report. Table 2 lists some of the topics selected by the students in Fall 2001.

Table 2. Topics for Biotechnology Reports

1. The Biology of Anthrax
2. Barcoding with Proteins
3. AIDS Vaccine
4. Golden Rice: A Wonder of Biotechnology
5. Stem Cells and Their Medical Applications
6. Peanut Allergies: Reactions and Remediations
7. Combinational Chemistry: A Process to Speed up Drug Development
8. Production of Polylactic Acid, a Biodegradable Polymer, from Biomass
9. Bio-Chips
10. Animal Pharming: The Industrial Utilization of Transgenic Animals
11. Bioinformatics and the Human Genome Project
12. Diabetes Mellitis: New Treatment Methods
13. Artificial Cells: Applications in Red Blood Cell Substitutes
14. Agrobacterium: Genetic Engineering in Agriculture

The chemical engineering courses in Bioseparation Engineering and Membrane Process Technology have both been taught in recent years by adjunct professors from industry. The textbook by Belter, Cussler and Hu[7] is used for the bioseparations course. Topics cover downstream separation processes used for removal of insolubles, product isolation, product purification and polishing, and experiments include microfiltration of yeast slurries,[8-9] ultrafiltration of dairy products,[10] and ion exchange chromatography. The textbook by Mulder[11] is used in Membrane Process Technology. Topics cover chemical and biochemical separations, so it is not strictly a biotechnology course although other institutions include it in this category. Classroom demonstrations include the casting of a cellulose acetate membrane and a tour of the four membrane experiments (reverse osmosis, gas permeation, microfiltration, and ultrafiltration) in the Unit Operations Laboratory. The course in Biological Treatment Processes is under development and will cover the theory and applications of the biological methods used in the treatment of potable and industrial waters and wastes, including biofiltration, bioremediation, bioventing, suspended and attached growth systems, and associated research topics.

Biochemical Engineering Laboratory

The Biochemical Engineering Laboratory was funded by an NSF instrumentation grant with matching funds from Manhattan College.[12-13] A series of experiments in fermentation and downstream processing was developed with up-to-date instructional equipment and supporting instrumentation. The experiments include bacterial fermentation, yeast production, mass transfer in bioreactors, continuous in-line cell disruption, semicontinuous centrifugation, ultrafiltration, microfiltration, and ion exchange chromatography. Kinetics of Batch Fermentation, based on an experiment developed at NJIT by Hanesian and Perna[14], is run with *E. coli* (a nonpathogenic strain) as well as *S. cerevisiae* (Baker's yeast) and includes HPLC (high performance liquid chromatography) analysis of the fermentation broth for substrate and product concentrations. Students are shown taking a cell sample in Figure 1 and analyzing the broth in Figure 2. Another experiment, Oxygen Transfer in Bioreactors, utilizes Baker's yeast in the exponential growth phase to generate dynamic data for measuring mass transfer coefficients[15-16]. Coefficients are also determined from static data using fermentation media without cells. The membrane experiments, Ultrafiltration And Microfiltration[8-10], are normally run by seniors in the Chemical Engineering Unit Operations Laboratory courses.

Figure 1. Batch Fermentation Experiment

Figure 2. High Performance Liquid Chromatography

Graduate and Undergraduate Research Topics

Bio-oriented research projects are available to the undergraduates and full-time graduate students through collaborations with the Biology Department at Manhattan College and the Earth Engineering Center at Columbia University. Some of these projects are summarized below:

1 - Mercury Methylation in River Sediments: This project aims at understanding the speciation chemistry and partitioning of mercury species in river sediments and the role of microbiological systems, mainly sulfate reducers, in the formation and bioaccumulation of the toxic compound methyl-mercury in fish. Thermodynamic calculations were performed and methylation reaction mechanism and rate were investigated. An analogy between the New York/New Jersey Harbor and the Patuxent River estuary was also sought.

2 - Organic Carbon Fractionation in Drinking Water: This project looks at the fractionation of various surface water samples obtained from various locations in the Eastern United States, into humic (hydrophobic) and non-humic (hydrophilic) via a XAD-8 resin adsorption technique. Each fraction is then analyzed for its assimilable (or metabolizable) organic (AOC) and dissolved carbon (DOC) content to verify the hypothesis that AOC is correlated to the hydrophilic fraction of DOC. Methods used include UV-254 absorption and a bioassay using *Pseudomonas fluomesurs* (P-17) and *Spirillium* (NOX) grown in the hydrophilic and hydrophobic water fractions and such as sample cell count is proportional to AOC concentration.

3 - Effect of Chaotic/Intermittent Mixing on the Growth of Yeast and Bacteria under Controlled Conditions: The first phase of this project looks at the effect of chaotic mixing on the fluid flow pattern of a blue dye in a water medium. The mixing is created in a reactor that uses two rotating cylinders, an inner spinning shaft and the reactor itself which constitutes the outer cylinder. The second phase tests the effect of chaotic mixing on cell growth in the same reactor fitted with a large gas diffuser. Cells in their exponential growth phase are added to the reactor and various mixing patterns will be tested through turbidity and HPLC analyses.

4 - Interpretation of False Negative and False Positive Results in the Total Coliform Membrane Filtration Analysis: This project looks at confirmation results of total coliform membrane filtration analyses performed on treated wastewater samples, with lauryl tryptose broth and brilliant green bile broth, following Standard Methods. Those results indicate a lack of confirmation in 50% of the tested positive colonies and led to further investigation of the potential for false negative and false positive results with the confirmation procedure using a Vitek identification system.

5 - Study of Chlorinated Organics Structure and Biological Reactivity: This project uses computational modeling techniques to study the molecular characteristics and energies of an array of chlorinated organic compounds ranging from dioxins and polychlorinated biphenyls to simple chlorinated methanes. Biological reaction rates and toxicology are then correlated to parameters of interest such as dihedral angle, molar volume, and lowest occupied molecular orbital (LUMO).

Conclusion

The projected decline in the number of openings in traditional chemical engineering fields[17], paralleled with the projected growth of the bioengineering industry in the coming decades, estimated to reach 35% of the U.S. industry in the year 2020[18], have led the chemical engineering department at Manhattan College to implement changes in the curriculum. These changes will better prepare our students for a competitive job market. A biotechnology concentration, coupled with a research component at both the undergraduate and graduate level, will put the students at a considerable advantage, besides instilling in them a fascination for living systems and the thrill of discovery through independent investigation.

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