Introduction to Biotechnology and Bioprocess Engineering – A Course for the Chemical Engineering Curriculum

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Introduction

Since the first gene was cloned in 1973, and a foreign gene expressed in a different bacteria species a year later, tremendous growth and interest in biotechnology have occurred [1]. Advances in genetics and molecular biology have led to many new pharmaceutical, chemical and agricultural products of micro-organisms and cultured plants, animal and insect cells [2]. The industrial production of these products will depend on bioprocessing strategies to enable commercially viable biomanufacturing. These strategies will include new engineering initiatives in the development of high throughput bioreactors, efficient separation and purification for bioproducts, and computer-interfaced instrumentation for optimal bioprocess control [2].

The importance of biotechnology in today's world and the need to meet the above challenges resulted in biochemical engineering being introduced into almost all syllabi for chemical engineering studies [1-3]. This development in chemical engineering departments has been matched by biotechnology education and training programs in community colleges, according to the Biotechnology Institute based in Arlington, VA as a great way for a two-year graduate to get a job in the growing biotech industry [4].

A factor which has contributed to the neglect of biochemical engineering courses in some chemical engineering departments is the assumption of a significant prior background in biological sciences. Although many chemical engineering faculty and students have not studied biochemistry and microbiology, a working familiarity with both fields is necessary in biochemical engineering [5]. In order to prepare students at Prairie View A&M University (PVAMU) for careers in the growing biotechnology and biopharmaceutical industries, a new course titled "Introduction to Biotechnology and Bioprocess Engineering" was developed and introduced in the chemical engineering program at PVAMU.

History of the Course

In the Spring semester of 2002, our department introduced "Introduction to Biotechnology and Bioprocess Engineering" as a topical course usable as a technical elective. The course is open to senior students in the non-engineering biological sciences and chemistry, and junior and senior chemical engineering students; and has been designed to provide the students training and hands-on skills in the areas of biochemistry, microbiology, molecular biology, and chemical engineering with an interdisciplinary approach.

The course was developed in collaboration with the College of Agriculture Research Center (CARC) at PVAMU which contributed expertise in molecular biology and applied microbiology and also attracted chemistry and biological sciences students. In addition, our collaboration with CARC ensured that students had the opportunity to visit well-equipped fermentation and molecular biology laboratories to complement the lectures on applied microbiology presented by our CARC collaborator. The course which has been taught every other Spring semester has attracted 10-15 students when offered. The course has been well

received by the students, with one so far student successfully obtaining admission to graduate school to pursue graduate studies in environmental biotechnology.

Course Objectives and Content

Course Objectives

Achievement of the full benefits of biotechnology requires substantial manufacturing capability involving large-scale processing of biological material. Employment of graduates trained in biochemistry, microbiology, molecular genetics and the biological sciences by companies to work in co-operation with biochemical engineers and chemical engineers highlights the multidisciplinary nature of bioprocessing. This course is designed to provide the student of chemical engineering, biological sciences or chemistry training to ensure effective communication, hands-on skills, and analytical tools necessary for a successful career in the biological/biochemical and biopharmaceutical process industries.

After completion of the course, the student should be able to demonstrate the following abilities.

- Understand the principles of bioprocess engineering, and for the biological sciences and chemistry student demonstrate an awareness of engineering concepts and ways of thinking
- Communicate on a professional level with process engineers and know the type of expertise they can offer
- Understand the engineering approach to process analysis and carry out routine calculations and checks on processes, in the case of the biological science or chemistry majors
- Critically evaluate new bioprocessing proposals, including the use of genetically modified organisms, and work at the interface of biology and engineering science
- Characterize growth and production behavior of cells whether genetically engineered or not as a function of the culture environment
- Understand process development from shake-flask through bench-scale and the criteria for pilot-scale work
- Understand the principles involved in scale-up to industrial operation and the importance of the use of scale-down procedures in bioprocessing
- Demonstrate knowledge and understanding of importance of utilities and sterilization in bioprocessing
- Demonstrate knowledge and understanding of the unit operations in downstream processing for product recovery, and effluent disposal
- Demonstrate a thorough knowledge of Food and Drug Administration regulations per current good manufacturing practices (cGMP) and documentation under validation, and National Institutes of Health Biohazard containment guidelines

Course Outcomes and Assessment: ABET CRITERION 3

The course has been designed to incorporate continuous assessment of students using homework assignments and exams to evaluate competence certain of the ABET[1] 2000

[1] ABET, Inc., 111 Market Pl., Suite 1050, Baltimore, MD 21202, (410) 347-7700, (410) 625-2238 (Fax)

outcomes-based evaluation criteria. These state that it should be demonstrated that students have acquired the following abilities and attributes.

- Ability to identify and solve engineering problems (criterion *e*)
- The broad education necessary to understand the impact of engineering solutions in a global/societal context (criterion *h*)
- Knowledge of contemporary issues (criterion *j*)

Detailed Course organization

Organization of the course is represented by the outline shown in Exhibit 1.

Exhibit 1. Course Outline Showing Course Organization

I. Introduction
- Bioprocess development - An inter-disciplinary challenge- Steps in Bioprocess Development

II. Basic Microbiology
- The place of micro-organisms in nature
- Microbial diversity and important classes of microbes
- The structure of cells
- Pure culture and aseptic technique

III. Basic Biochemistry I
- The elements of life
- Elemental composition of microbial cells
- The chemicals of life
- Microbial nutrition

IV. Application of Chemical Engineering Principles I
- The use of material balance, elemental composition of cells and microbial nutrition requirements in fermentation medium design
- Yield coefficients
- Fermentation medium design and formulation

V. Basic Biochemistry II
- Nucleic acids: DNA and RNA
- Proteins and protein synthesis
- Enzymes and enzyme kinetics
- Catabolic and anabolic pathways
- Microbial growth and kinetics

VI. Basic Molecular Biology
- Genes and gene expression
- Genetic systems, Genetic analysis and studying genes
- Plasmids, recombinant DNA techniques and Genetic Engineering

VII. Application of Chemical Engineering Principles II
- Energy Balances: General energy balance equation and heat transfer
- Maintenance of fermentation temperature
- Heating, cooling and refrigeration
- Sterilization

VIII. Application of Chemical Engineering Principles II
- Mass Transfer: Role of diffusion in bioprocessing
- Aeration and agitation of fermentation media and oxygen transfer in fermentors

IX. Application of Chemical Engineering Principles III
- Bioreactor Engineering: Bioreactor configurations and operation
- Practical considerations for bioreactor design and construction

X. Application of Chemical Engineering Principles IV
- Introduction to downstream processing
- Cell disruption, Filtration and centrifugation
- Liquid-liquid extraction, Adsorption and Chromatography

XI. Regulatory Compliance
- Regulators and their Guidelines
- U.S. Food and drug Administration (FDA's) Current Good Manufacturing Practices (cGMPs)
- Code of Federal Regulations Title 21 (CFR 21)
- Validation and cGMPs

Implementation: Feedback, Challenges and Opportunities

"Bioprocess Engineering: Basic Concepts" by Shuler, M.L. and F. Kargi (Second Edition, 2001, Prentice Hall PTR) is the recommended textbook for the course while "Bioprocess Engineering Principles" by Doran, P.A.(1995, Academic Press) is the recommended reference textbook. The two books have been well received by students taking the course.

The first observation was the motivation of the chemical engineering students to learn basic microbiology and biochemistry following the introduction of the class to the steps in bioprocess development, and their realization of bioprocess development as an inter-disciplinary challenge. Secondly, the early introduction of the use of material balances and knowledge of the elemental composition of microbial cells in medium formulation was especially helpful since the students could immediately apply knowledge acquired in a course in chemical engineering to a biological system. Finally, homework assignments which involved students presenting essays on topical issues such as genetically modified organisms and foods, or genetic engineering, followed by classroom discussions increased student interest.

The main limitation of the course has been the absence of a laboratory component. Recently acquired laboratory equipment in the department through a National Science Foundation major research instrumentation grant has enabled us to begin to incorporate biotechnology laboratory methods practice into the teaching of the course.

Interest shown by students in taking the course has made its conversion from a topical to a regular course in our curriculum as the next logical step. Further, in line with the College of Engineering at PVAMU's goal of establishing a Center of Excellence in Biotechnology and Biochemical Engineering, the department plans to present the course alongside courses in microbiology and biochemistry to enable students graduate with a BS in chemical engineering with a biochemical/bioprocess/biomedical concentration.

References

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