Instruction manual for ABCT247

Introduction to Chemical & Bioprocess Technology

Credit value: 3 **Class hours (Le/Tu):** 42

Requirements: Compulsory for BScCT, BScABB and HDCT

Marking scheme:

Continuous Assessment:	40%
(Assignments 5-10% + Tests 30-35%)	
Final Exam:	60%

Most tests and exams are close-book, and some are partially open.

Contents and schedule:

Chapter and Topic	Lec/Tu hrs	Assignment
1. Introduction to Chemical and Bioprocess Technology	1-2 hrs	
2. Introduction to Engineering Calculations	4-6 hrs	As#1 & **Quiz 1**
3. Separation Processes	4-6 hrs	As#2
4. Material Balances	6-9 hrs	As#3
Test 1	2 hrs	
5. Energy Balances	6 hrs	As#4
6. Heat Transfer	6 hrs	
7. ~~Evaporation~~	~~2 hrs~~	~~As#5~~
Test 2	2 hrs	

Chapter contents and organization:

- Main texts for principles and concepts (Lectures)
- Exercise questions and Examples (Tutorials) (with answers/solutions)
- Summary of contents
- Review questions (guide for self-studies)
- Assignments (Homework) (Solutions distributed after submission)

Chapter 1 Introduction to Chemical and Bioprocess Technology

About this course (or subject)

- **Aim and scope:** An introductory course covering the basic principles and common processes of chemical engineering applied to the chemical and bioprocess industries and many others, such as food, pharmaceutical and environmental industries.
- **Prerequisites (useful but not compulsory):** High-school physics, mathematics, chemistry and biology; physical chemistry 1.
- **Main features:** broad-based and introductory; emphasizing physical principles, some mathematics and engineering, and some chemistry and biology basics; lots of exercises (with calculation).
- **Target students:** Applied sciences (such as chemical technology and biotechnology); Entry-level chemical engineering.
- **Intended learning outcomes:**

Upon completion of this subject, students will be able to

1) recognize the common chemical and biochemical processes and the functions of individual process equipment;
2) apply the elementary chemical engineering principles and concepts to analyze and solve material and energy balance problems in chemical, biochemical and related processes;
3) estimate the size of process equipment, the amounts and costs of material, and energy in chemical and bioprocess plants.
4) express engineering data in a meaningful way.

Typical questions you will encounter:

1) Given a raw material or practical task, design a simple process to attain the desired product or to fulfil the task with both diagram and description.
2) Given a process flow diagram, describe the overall process, and the names and functions of major process units.
3) For given amount and composition of raw materials, find out the amount and composition of products, or vice versa (material balance).
4) Fluid A is heated or cooled by fluid B in a heat exchanger, calculate the heat transfer area, the flow rate of fluid B or the outlet temperature of A or B (heat transfer and energy balance).

Successful ways to learn this course: Understanding the *concepts* is most important. Solving engineering problems involves many equations and numbers, and you should use the equations only when you have a clear understanding of them. You can never learn just by trying to match each term with a given number. To understand the concepts, you should

- be attentive during the lectures and participating in the tutorials;

- study the lecture notes and relevant reference books;
- do a lot of exercises (in the assignments, tutorials and books);
- memorize the definitions of common physical terms and process variables, the values of some physical properties and unit conversions.

Textbooks and References

1. Geankoplis CJ: Transport Processes and Separation Process Principles or Unit Operations, 3rd-4th ed. Prentice Hall 1993-2003.
2. Doran PM: Bioprocess Engineering Principles Harcourt Brace & Company, 1998
3. Felder RM & Rousseau RW: Elementary Principles of Chemical Processes, 2nd ed. John Wiley & Sons 1986. (Units, material and energy balances)
4. Himmelblau DM: Basic Principles and Calculations in Chemical Engineering, 5th/6th ed. Prentice Hall 1989/96. (Equivalent to ref.2 but may be not as easy to read)
5. McCabe WL, Smith JC Harriott P: Unit Operations of Chemical Engineering, 5th ed. McGraw-Hill 1993. (Equivalent to ref.2 but not as easy to read)

(Additional references for particular contents are listed within the chapters.)

1. Basic concepts of process technology and chemical engineering

1.1. What is process technology?

Process technology deals with the processes, equipment and operations involved in the chemical and other processing industries such as pharmaceutical, biochemicals, environmental protection and pollution control, textiles, papers, food, etc. Chemical processes have been used for a long time to provide many useful products and services (**Table 1**).

- **A process** is a series of operations that causes physical and/or chemical changes in a substance or a mixture of substances to desired product (desired composition, properties and form). For example, a waste water treatment process is shown in **Fig. 1**.
- The materials that enter a process are referred to as the **input** or **feed** to the process, and those leave are called the **outputs** or **products**.

Process technology was originally a subject of chemical engineering or **chemical process technology**.

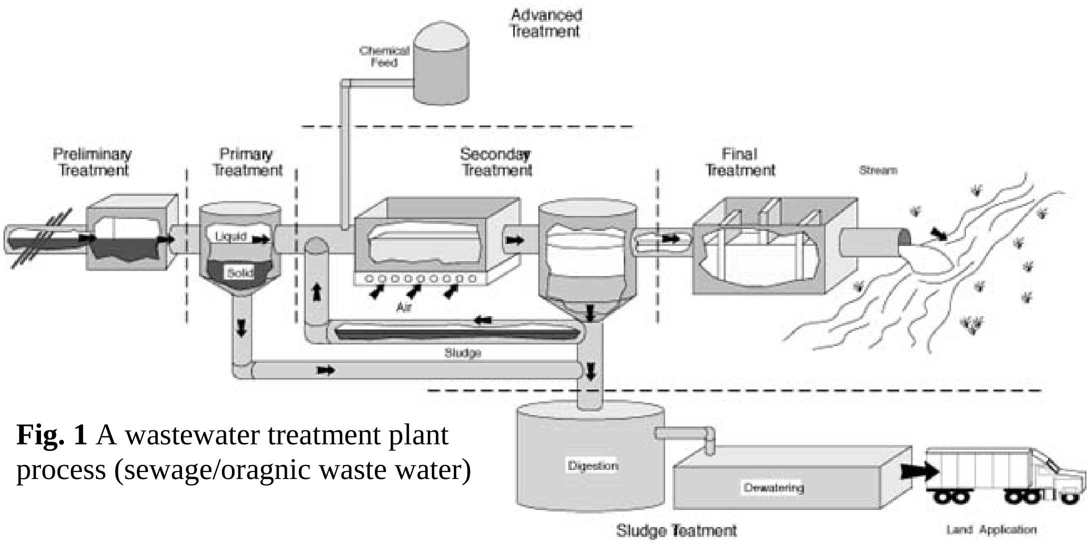

Fig. 1 A wastewater treatment plant process (sewage/oragnic waste water)

(Ref: http://ga.water.usgs.gov/edu/wwvisit.html)

Table 1 Products or services with chemical processes (Moulijn JA et al. Chemical process technology. Chichester: John Wiley & Sons, 2001)

Sector	**Product or service**
Raw materials	– Inorganic: air, water, and minerals
	– Organic: fossil fuels (hydrocarbons): oil (petroleum), natural gas and coal,
	– Biomass: plants, animals and microorganisms
Products derived from fossil fuels	– Fuels: LPG (liquefied petroleum gas), gasoline, diesel, kerosene
	– Base chemicals (bulk chemicals): ethene, propene, butane, benzene, synthesis gas, ammnina, methanol
	– Intermediates (bulk chemicals): acetic acid, formaldehyde, urea, ethane oxide, acrylonitrile, acetaldehyde, terephthalic acid
	– Consumer products: plastics, electronic materials, fibers, solvents, detergents, insecticides, pharmaceuticals
Other chemical products	– Chlorine, sulfuric acid, nitric acid
	– Fine chemicals (bulk): drugs, vitamins and pesticides, flavors, fragrances, and active ingredients
	– Specialty chemicals: adhesives, disinfectants, pesticides, pharmaceuticals, photographic chemicals, dyestaffs, perfumes, and specialty polymers

1.2. Chemical engineering and process technology

Chemical engineering deals with the *physical and chemical processes* in which raw materials are *changed or separated* into useful products. It focuses more on the physical aspects of the processes (transport processes; equipment design), and widely applies mathematical tools to quantify the process parameters, conditions and performance. Chemical engineering is both an art and a science for the design, analysis, scaling-up, optimization and control of processes and equipment (to put chemical technology into industrial application and large scale operation).

The **duties of chemical engineers** may include,

- to develop, design and engineer both the complete process and the equipment used for raw material preparation, chemical reactions, product recovery and processing, and effluent treatment;
- to choose the appropriate raw materials;
- to operate and control the plants efficiently, safely and economically;
- to enforce the product quality measures.

The **tasks and approaches of engineers**: to solve practical problems with feasible methods and approaches, using scientific principles, and empirical knowledge and logical judgement; *to make it work.*

Important Areas of Chemical Engineering Science:

- **Reaction engineering:** reaction kinetics, reactors design and analysis
- **Transfer processes:** heat, mass and momentum transfer theories
- **Unit operations or separation processes:** processing of raw materials and separation and processing of products
- **Thermodynamics:** chemical and thermal energies involved in chemical/physical processes, the limit that a change may reach (or the potential).

Principles of chemical engineering. The execution of all chemical engineering processes is governed by the general laws of nature, **conservation of mass, energy and momentum**. Evolving from these laws is the **balance of materials, energy and momentum**. In addition to these general laws, there are many empirical laws, rules and principles derived from scientific and logic deduction. We will learn how to apply these principles to solve process problems.

1.3. Composition of chemical plant process

A complete chemical plant process generally consists of the following processes (**Fig. 2**),

1) Raw material processing/preparation;
2) Chemical reactions (in one or more reactors) for product formation;
3) Product separation and processing;
4) Effluent treatment.

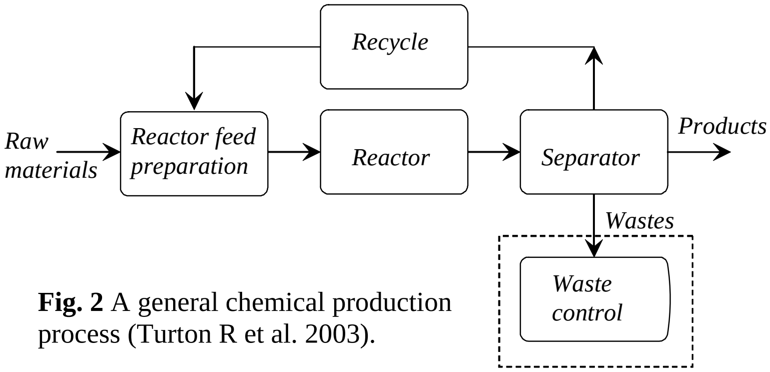

Fig. 2 A general chemical production process (Turton R et al. 2003).

1) Reactor feed preparation block is to bring the feed conditions such as concentration, temperature, and pressure to suitable levels required in the reactor. In most cases, the raw materials are from a storage.
2) Reactor block: All chemical reactors take place in this block. The stream leaving this block contains the product(s), byproducts and unused feed materials.
3) Separator block: for the separation of products, byproducts, unused feed materials and wastes, by a variety of physical processes (unit operations).
4) Recycle block: to return the unused feed materials to the reactor block for reuse.
5) Waste control block: Most chemical production processes generate wastes which must be treated before being discharged to the environment.

Fig. 3 shows a chemical plant process for ethanol production by direct hydration of ethylene. The process usually consists of a reaction section in which crude ethyl alcohol is formed, and a purification section with a product of 95% (volume) ethyl alcohol (EtOH-H_2O azeotrope). For many industrial uses, the 95%-purity product from the purification section is good enough, or an additional dehydration section is used to produce high-purity or water-free ethyl alcohol.

(**Q:** Describe this process in general terms of process technology, and the functions of process major units, and identify the input, output and recycle streams)

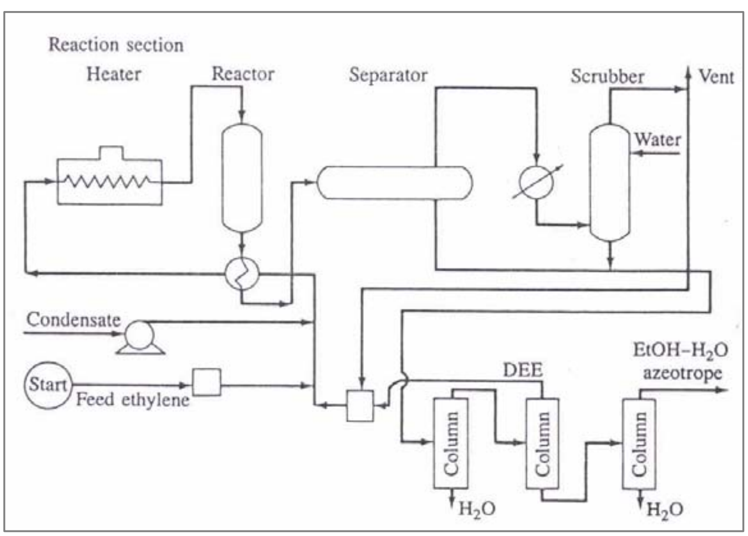

Fig. 3 Flow diagram for ethanol production by ethylene hydration (Moulijn JA et al. Chemical process technology. John Wiley & Sons, 2001). Main reaction $CH_2{=}CH_2 + H_2O \rightarrow CH_2CH_2OH$, and the main side reaction $2C_2H_5OH \rightarrow (C_2H_5)_2O + H_2O$; (DEE-diethyl ether; reaction conditions: T average 300 to 400^oC; p 1000 psi).

In this direct hydration process, a supported acid catalyst usually is used. Only 4% of the ethylene is converted to alcohol per pass through the reactor, but this cyclic process eventually gives an overall yield of 97%. Important factors affecting the conversion include temperature, pressure, the water/ethylene ratio, and the purity of the ethylene. (Chemical and Process Design Handbook Speight, J.G. 2002 McGraw-Hill).

2. Bioprocess technology

2.1. Biotechnology and bioprocesses

Biotechnology may be broadly defined as the utilization of living organisms such as microbial, plant, animal, or their constituents to make products and provide services. Based on this definition, the beginning of biotechnology may be recorded as early as 6000 BC when our ancient ancestors used yeast to make beer. However, *modern biotechnology* usually refers to the processes and techniques involving genetically-engineered species (organisms), through recombinant DNA or cell fusion method.

Fig. 4 Discovery of the double helix DNA structure by Watson and Crick (courtesy of Cold Spring Harbor Laboratory Archives).

Biotechnology has reached every part of our modern society. The rapid development and increasing application of biotechnology would not have been possible without the remarkable scientific discoveries and technical breakthroughs in the biotechnology history (**Table 2**).

(**Q**: Find applications or products of biotechnology in your daily life.)

Table 2 Milestones in Biotechnology (National Health Museum Website)

Year	Event
1953	James Watson and Francis Crick discover the molecular structure of DNA (Fig.4).
1965	Harris and Watkins successfully fused mouse and human cells.
1966	The genetic code is deciphered through biochemical analysis revealing the specific codons for amino acids.
1972	Stanley Cohen and Herbert Boyer combine their efforts to create recombinant DNA. This technology will be the beginning of the biotechnology industry.

(In 1976, the first biotechnology firm Genentech was established in the United States, to apply recombinant DNA technology in manufacturing processes.)

A **recombinant DNA (rDNA)** is an artificial DNA sequence generated from the combination of two or more DNA sequences from different sources. For the construction of a rDNA, the DNA from both sources is first cleaved (cut) with the same restriction endonuclease (restriction enzyme) into DNA fragments with defined length and specific endpoints, and the DNA fragments are then ligated (joined) covalently with DNA ligases into a recombinant DNA molecule. With the recombinant DNA technology, we are now able to manipulate life at its very basic level, the gene. Fig.5 shows the major routes of modern biotechnology products.

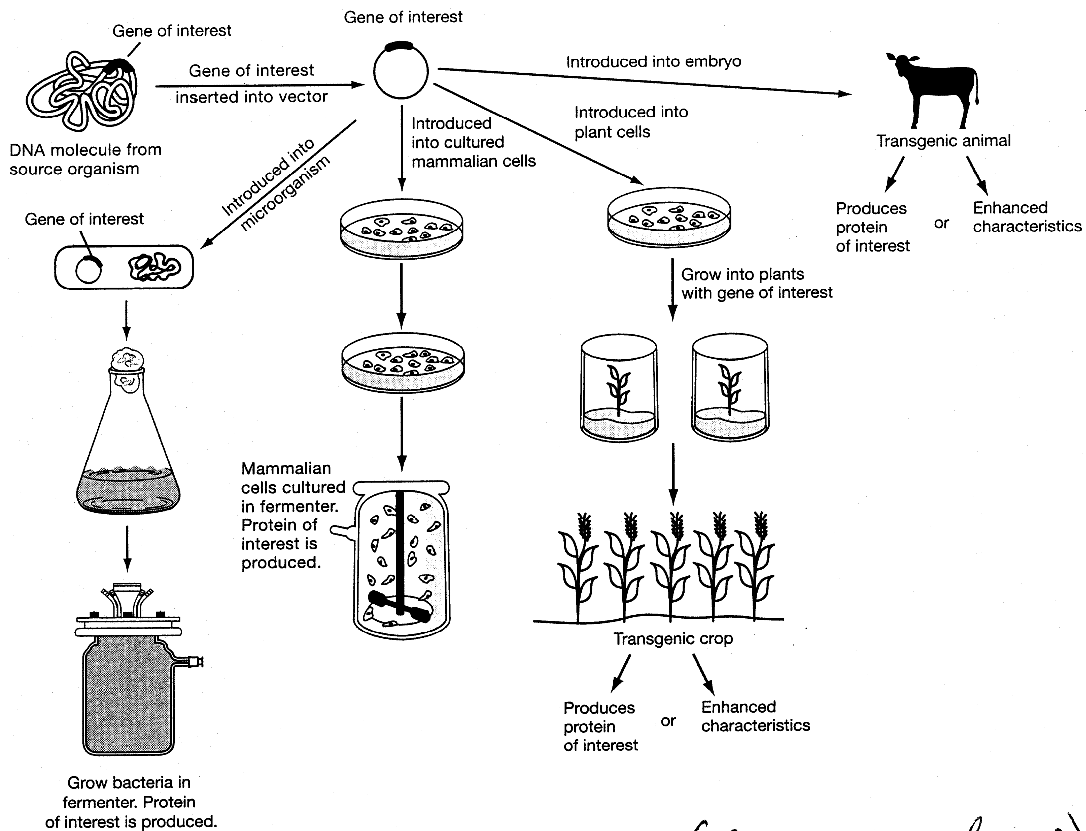

Fig. 5 **The Genetic Modification of Organisms Using Biotechnology.** (Seidman et al. 2000)

When our ancient ancestors made alcoholic beverages, they used a bioprocess: the combination of yeast cells and nutrients (cereal grains) to form a *fermentation system*. As the yeast cells consumed the nutrients for their own growth, they generated by-products including alcohol (C_2H_5OH) and carbon dioxide gas (CO_2) which are the major components of alcoholic beverage. Bioprocesses have become widely used in several fields of commercial biotechnology, such as the production of enzymes and antibiotics (**Table 3**), and the fields and number of application are expanding and increasing as life sciences and engineering techniques advances. (BIO. "What is Biotechnology?" Washington, D.C.: Biotechnology Industry Organization, 1989).

Products and services from bioprocess technology

– Growth of biomass, e.g., baker's yeast and SCP (single cell proteins).

– Production of biochemicals and metabolites, e.g., microbial enzymes (amylase and protease), primary metabolites (e.g., ethanol, amino acids, organic acids); secondary (antibiotics); Recombinant proteins as such as bioassay and therapeutic reagents.

– Bioconversion and biotransformation, such as foods/beverages modified by microbial activity: coffee, tea, cocoa, vanilla, cheese, olives and tobacco, and wastewater treatment.

In most bioprocesses, enzymes are the catalysts for all biochemical reactions in whole microorganisms or their cellular components.

Table 3 Products or services with bioprocesses (Scragg)

Sector	**Product or service**
Chemicals	Bulk: ethanol, acetone, butanol, organic acids (citric)
	Fine: enzymes, perfumeries
	Polymers
Pharmaceuticals	Antibiotics, enzymes, enzyme inhibitors, steroids, vaccines, monoclonal antibodies
Energy	Ethanol (gasohol), methane (biogas)
Food	Diary products (cheese, yoghurts, etc.); Bakers' yeast, beverages (beer, wine); Food additives, amino acids, vitamins; Protein (SCP)
Agriculture	Animal feeds (SCP), waste treatment
	Vaccines, microbial pesticides

Because bioprocesses use living material, they offer several advantages over conventional chemical methods of production (**Table 4**).

Table 4 General features of bioprocesses (in contrast with chemical processes).

Bioprocesses	Chemical processes
Multiple reaction steps, mild reaction conditions (low T and normal P)	Single steps, harsh reaction conditions (high T, p)
“Green” and renewable, environment friendly	Tend to generate more hazardous wastes
Low productivity and high cost	Rapid, low cost, commercially more competitive

However, there are also major challenges as follows.

1) The culture or reaction conditions must be strictly controlled, such as temperature, pH, and sufficient oxygen supply.
2) In most cases, the bioreactor must be kept strictly sterile to avoid contamination of the culture by other organisms.
3) The many reactions within the living organisms result in the formation of many unwanted by-products. This causes great complexity to the recovery and purification (separation) of the desired product.

2.2. Composition of a bioprocess plant

A bioprocess plant usually has the following steps, (1) Medium preparation: formulation (mix and dissolve nutrient components) and sterilisation. (2) Inoculum or seed preparation (incubators, shake-flasks and small fermentors). (3) Fermentation (large fermentors). (4) Product recovery and processing. (5) Effluent disposal/treatment.

(Example: Identify the process components and functions from Fig. 6, an example of bioprocess).

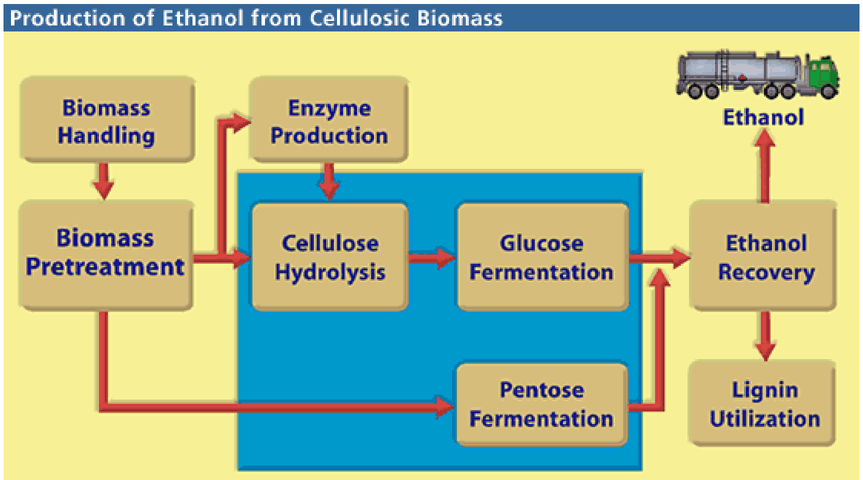

Fig. 6 Ethanol production by fermentation from cellulosic biomass.
(Ref: http://www.ethanolrfa.org/prod_process.html)

Terms about bioprocess technology:

- *Fermentation* is a biochemical process involving the biochemical conversion (metabolism) of a substrate into bioproducts by microorganisms such as bacteria and fungi.
- *Bioreactor* is a conditioned/controlled vessel or container for bioconversion or biotransformation by living organisms or enzymes. The bioreactors for microbial fermentation are commonly known as *fermenters*.
- *Culture vessel:* a general name for all sorts of culture containers including Petri dishes, tubes, flasks, small and large bioreactors.

2.3. Biochemical engineering in bioprocess technology

Biochemical engineering is the extension of chemical engineering principles to biosystems and processes. (Recall the statement made in an earlier part: chemical engineering deals with the *physical and chemical processes* in which raw materials are *changed or separated* into useful products.) Many products or techniques of biotechnology are developed through laboratory procedures which provide only small amounts, not sufficient or economical for practical uses. Biochemical engineering is to realize these lab-scale bioprocesses on an industrial scale, and to obtain large amounts of products economically and safely, at high purity and quality.

Biochemical engineering is often subdivided into *bioreaction engineering* and *bioseparations*, dealing with both the biochemical reactions for product formation and the separation and purification techniques for product processing.

Major areas/subjects of biochemical engineering:

1) Biocatalysts and biochemical reactions (Microbial, plant and animal cells; tissues, organs and whole of plants and animals; enzymes; Cellular and molecular structures Growth and metabolism; Modification and improvement)

2) Bioreaction engineering (Bioreactor design, operation and scale up; Process strategies: batch, continuous, fed-batch)

3) Downstream processing (separation technology) (Production isolation and purification; Product formulation and finishing).

4) Effluent treatment and pollution control processes

Engineering problems in bioprocesses:

1) Bioreactor design and operation (Design and operation: oxygen supply and heat removal; Construction and mechanical parts; Contamination and long-term operation; Change in the culture conditions and bioreactor dynamics upon scaling up)

2) Product recovery and purification (Sensitivity of bioproducts to temperature, pH; Stringent quality control regulations for biopharmaceuticals (GMP for good manufacture practice))

Summary and review (Chapter 1 Introduction to Chemical and Bioprocess Technology)

1) The organization and components of typical chemical and bioprocess plants, and their major functions in the whole process. (Read the flow charts of chemical/bioprocesses and recognize the process units and their functions. You must be able to describe these with your own words.)
2) Summarize and compare the common and different aspects between chemical and bioprocess plants; the applications of chemical engineering in process technology.
3) What are the roles or functions of process technology or chemical engineering in chemical or biochemical technology development?
4) Memorize the new terms (meaning or definition) in this chapter such as, reactor, feed, effluent, process, bioreactor, fermentor, fermentation, culture vessel, recombinant DNA technology, inoculum, culture medium, downstream processing.