Chapter 3: Types of Bioreactors
You will learn........

✓ Strategies for bioreactor design.

✓ Schematic diagrams of stirred and air-driven bioreactors, packed bed, fluidized bed and trickled bed reactors.

✓ Advantages between stirred and air-driven bioreactors.
Types of Bioreactors

1. Stirred tank bioreactor
2. Pneumatically (operated by air or gas under pressure)
   Agitated bioreactors:
   • Airlift bioreactor
   • Bubble Column
3. Immobilized Cell Bioreactors
4. Membrane Bioreactors
5. Photo-bioreactors
Strategies for Choosing a Bioreactor

- Microorganism species
- Growth and oxygen requirements
- Shear and rheology effects
- Cleaning and Sterility
- Light
- Foam
- Heating and cooling
- Materials of construction

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Several steps before it reaches the production fermenter.

The 1st step is cultivation of the organism in the lab. This is often done in shaker flasks under the direct supervision of microbiologist.

A portion of high density broth is then transferred from the shaker flask to a seed tank which is a small fermenter designed to increase the quantity of organisms.

From there, it is usually transferred to a larger fermenter called the inoculum tank. Finally the contents of the inoculum tank are transferred to the production fermenter.
Classes of Bioreactor

2 main classes of bioreactors.

AEROBIC
- presence of oxygen (to growth and produce product)
- Eg: yeast, antibiotics, enzyme and amino acids
- amount of oxygen required varies.

ANAEROBIC
- microorganism growth and create product.
- Eg: most fuel processes and manufacture of some organics acid.
Classification Of Bioreactors

• On the basis of mode of operation
  batch, fed batch or continuous.

• On the basis of mode of flow of fluids
  CSTR bioreactor (continuous flow stirred reactor-the content of the
  bioreactor is ideally mixed),
  bioreactor with piston flow (Plug Flow Bioreactor)

• On the basis of a number of phases treated
  homogeneous bioreactors (e.g. one phase tubular bioreactor with enzyme
  diluted in the liquid substrate)
  heterogeneous bioreactors (e.g. two phase solid-liquid bioreactor like the
  column type bioreactor with immobilized enzyme and liquid substrate
  and/or three phase bioreactors with submersed culture: gas (air bubbles)-
  liquid (substrate)-solids (cells)
1. Stirred Tank Bioreactors
Stirred Tank Bioreactors

- The most important type of bioreactor for industrial production processes.
- Low capital and operating costs.
- Depending largely on the amount of heat to be removed, the stirrer may be top- or bottom driven.
- Tanks are fitted with baffles, which prevent large central vortex as well as to improve mixing.
- High agitation and aeration cause major problems such as foaming, which may lead to unknown contamination.
Stirred tank bioreactor

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Standard Geometry of STR Bioreactor

✓ Cylindrical or curve base. Curve base assists in the mixing of the reactor contents.

✓ Constructed to standard dimensions according to recognized standards such as published by the International Standards Organization and the British Standards Institution.

✓ The dimensions take into account both mixing effectiveness and structural considerations.
Schematic Diagram of a Stirred Tank Bioreactor

- Cooling jacket
- Exhaust air filter
- Condenser
- Impeller
- Motor
- Cooling water in
- Cooling water out
- Baffles
- Sparger
- Inlet air
A bioreactor is divided into a **WORKING VOLUME** and **HEAD-SPACE VOLUME**.

**WORKING VOLUME** - fraction of the total volume taken up by the medium, microbes, and gas bubbles (70-80% of the total fermenter volume).

The remaining is **HEADSPACE**.

**Depends on the rate of foam formation** during fermentation. If fermentation has a tendency to form foam, a larger headspace and smaller working volume will need to be used.
Basic Features of Bioreactors

1. An agitation system
2. An oxygen delivery system
3. A foam control system
4. A temperature control system
5. A pH control system
6. Sampling ports
7. A cleaning and sterilization system
8. A sump and dump line for emptying of the reactor
2. Pneumatically Agitated Bioreactors:

• Airlift bioreactor
• Bubble Column
- **Mixing** is accomplished without any mechanical agitation.
- Used for **tissue culture** because the tissues are sensitive to shear stress, thus normal mixing is not possible.
- Air is fed into the bottom of a central draught tube through a sparger ring. The flow passes up through the draft tube to the head space of the bioreactor, where excess air, by-product and CO$_2$ disengage.
- In general, airlift bioreactors have the following **features**:
  - Internal loop or
  - External loop
  - Draft tubes

Schematic Diagram of a Air-Lift Bioreactor

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Advantages of an Airlift Bioreactor

- **Low shear**, which means it can be used for plant and animal cells.
- **Since there is no agitation, sterility is easily maintained.**
- **In a large vessel, the height of the liquid can be as high as 60m, the pressure at the bottom of the vessel will increase the oxygen solubility, thus increase the mass transfer.**
- **Extremely large vessel can be constructed.**
Disadvantages of Airlift Bioreactors

- **High capital cost** with large scale vessel.
- **High energy cost.** Although an agitator is not required, a greater air throughput is necessary, and the air has to be at higher pressure, especially if large scale.
- As the microorganism circulate through the bioreactor, the **conditions change**, and it is impossible to maintain consistent levels of carbon source, nutrients and oxygen throughout the vessel.
- The **separation of gas from the liquid is not very** efficient when foam is present.

In the design of an airlift bioreactor, these disadvantages must be minimized.

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Bubble Column Reactor

- Gas is introduced in the bottom section for mixing and aeration purposes.
- Used in production of Baker’s yeast, beer and vinegar.
- Also used in aeration and treatment of wastewater.
- In bubble columns, the hydrodynamics and mass transfer depend on the size of bubbles and how they are released from the sparger.
Difference between bubble column and airlift bioreactor

Differences on Schematic Diagram of a Bubble Column & Air-Lift Bioreactor

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Laboratory-Scale Air-Lift Bioreactor
(with external loop)
For mammalian cell cultivation
The Air-Lift fermenter is 200' high and 25 ft diam.

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3. Immobilized Cell Bioreactor (ICB)
Bioreactors with immobilized enzymes and cells

- Immobilization means associating the biocatalysts with an insoluble matrix, so that it can be retained for its economic reuse under stabilized conditions.
- Immobilization helps in the development of continuous processes.
- Some examples of the use of enzymes:
  - Removal urea from a wastewater stream
Immobilized Cell Bioreactor (ICB)

- Enzymes, viable cells, plant cells and animal cells can be immobilized.
- It can be divided into stirred tank reactors, fixed bed reactors, fluidized bed reactors. These reactors can also be combined or modified.
- The choice of reactor design for an ICB would depend on:
  - Mass transfer requirements, eg. Oxygen supply and gas removal
  - Particle characteristics, eg. In stirred tank reactor, damage to the particle is greater than in packed bed reactor.
  - Kinetic considerations

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Packed Bed Bioreactors

- Cells are immobilized on large particles (not move in liquid).
- Simple to construct and operate but can suffer from **BLOCKAGE** and **POOR OXYGEN TRANSFER**
Schematic Diagram of a Packed Bed Bioreactor

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Trickle-Bed Bioreactors

• Is another variation of the packed bed bioreactors.

• Liquid is sprayed onto the TOP of the packing and trickles down through the bed in small rivulets (flow in small stream).

• Simplest reactor type for performing catalytic reactions where GAS and LIQUID (normally both are reagents) are present in the reactor and it is extensively used in PROCESSING PLANTS

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Fluidized Bed Bioreactor

One of method of maintaining high biomass concentrations and at the same time good mass transfer rates in continuous cultures

Mixing is assisted by the action of PUMP.

Cells/enzymes are immobilized IN or ON the SURFACE of LIGHT PARTICLES

PUMP is located at the base of tank causes the immobilized catalysts to move with the liquid. (pump push the fluid and particle in a vertical direction)-good circulation
Fluidized-bed bioreactor with immobilized cells
Methods of Immobilization

Active Immobilization
- Cross-linking
- Covalent bonding
- Entrapment in Gels

Passive Immobilization
- Adsorption
- Colonization

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Advantages of immobilized Cell Bioreactor

- Application to multi-step enzyme reaction may be possible.
- The enzyme activity yield on immobilization is high.
- Operational stability is generally high.
- Operations for enzyme extraction and/or purification are unnecessary.
- High cell densities can be employed.
- Cell densities and enzyme activities can be expected to be maintained over a long period of operation.
- Products can be easily removed from immobilized cells.
- Immobilized cells appear to be less susceptible to microbial contamination.
Disadvantages of Immobilized Cell Reactor

- The cells may contain numerous catalytically active enzymes, which may catalyze unwanted side reactions.
- The cell membrane itself may serve as a diffusion barrier, thus reducing productivity.
- Contamination by cells leaking out from carriers may occur.
- The physiological state of the microorganism cannot be controlled.
Immobilized Plant Cell Culture
Immobilized yeast cells
4. Membrane Bioreactor
Membrane Reactors

- A membrane reactor is a **flow reactor within which membranes** are used to **separate cells or enzymes from the feed or product streams**.
- Usually a **continuous system**.
- **Products may also be removed continuously**, but in some applications they must be harvested intermittently or at the end of the run.
- **Polymeric microfiltration (0.1 – 5 μm)** or **ultrafiltration (20 – 1000 Å)** membranes are most commonly used.
- Membranes are obtained in **hollow-fiber or flat-sheet form**.
- Application in enzymatic reaction, **production of primary and secondary metabolites by microorganisms and plant cells**, **generation of antibodies by mammalian cells**.
• It is supposed that the enzymes/cells are freely entrapped in the cavities of the support part of asymmetric membranes.

• The substrate in the aqueous phase is forced to flow across the membrane and react with enzyme/cells and consequently flow to the inner part of the hollow fiber and out of the membrane.

The term membrane bioreactor (MBR) frequently defines a combination of an activated sludge process and membrane separation.
Due to recent technical innovations and significant cost reductions, the applicability for the **MBR technology in municipal wastewater treatment** has sharply increased.

Separate cells or enzymes from the feed or product streams.

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Cross section of hollow fibers in FiberCell® Systems cartridge.
Advantages of Membrane Reactors

• A consequence of the retention of cells or enzymes within the reactors. This allows the reactors to be continuously perfused without worrying about washout.

• Membrane also provide an in-situ separation of the cells or enzymes from the product.

• Compared to immobilization technique, no chemical agents or harsh conditions are employed.

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Challenges in Membrane Reactors

- Cells and enzymes entrapped within membrane reactors are subject to diffusion and convection that can render their distribution heterogeneous.

- An uneven flow distribution among the various channels in a membrane reactor can have significant effect.
5. Photobioreactor
• Designed for applications such as wastewater treatment, water quality management, remediation of contaminated soil.

• **Organisms used:** green and blue-green (bacteria) algae, photoautotrophs, photoheterotrophs

• Culture systems utilizing ponds or rectangular tanks with limited mixing.

• Deep channeled culture systems with a closed circulating loop and better mixing.
Micro-algae are source of **unique metabolites** that can be used to **produce novel high-added value bioactive compounds with industrial potential** in medical technologies or as food, feed or cosmetic ingredients or as potential source of biofuels.

**Production of novel PUFAs** (Poly-Unsaturated Fatty Acids) by micro algae is highly challenging as current production processes from fish oil threatens natural marine organism’s populations.

**Algae can accumulate large amounts of polysaccharides, lipids and proteins** with potential as nutrients/energy or biofuel source

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Photobioreactor

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Flat Panel Photobioreactor
Tubular photobioreactors
Industrial Bioreactor

Glacial Lakes Energy in Watertown, South Dakota
47+ million gallon per year ethanol production.

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Fermentation...

The essence of bioprocessing....predates the discipline of chemical engineering
Thank you

References;


