TYPES OF BIOCHEMICAL REACTORS

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Abstract

This paper gives an overview of the types of reactor used in biochemical and related industries. Two categories; batch and continuous reactors are discussed and the advantages and disadvantages for each type are highlighted .

Introduction

A bioreactor is a device in which materials are treated to promote biochemical transformation by the action of living cells or by in vitro cellular components such as enzymes. Bioreactors differ from chemical reactors chiefly in that they operate at low temperatures and pressures.

Bioreactors are widely employed in the food and fermentation industries, in waste treatment and in many biomedical facilities. In industrial processes, they are invariably at the heart of the process (Figure 1). In general, there are two types of bioreactors; for fermentation (live cell) and enzyme (cell-free) transformations.

In fermentation reactors, cell growth is promoted or maintained to allow formation of products, either a metabolite (e.g. antibiotic, alcohol), or single cell protein, or transformed substrate (e.g. steroids) or purified solvent (e.g. in water treatment).

In enzyme reactors, substrate formation is promoted without the cell life-support system. Frequently, these reactors employ immobilised enzymes where solid or semi-solid supports are used to entrap or attach the biocatalyst so that it is not lost and may be reused.

Virtually all bioreactors deal with heterogeneous systems involving at least two, and usually three phases. To provide optimal conditions for the required biochemical changes, interphase transfers of mass, heat and momentum must occur. Various studies and work have been done in the area to improve the performance of the reactors.

In industrial practice, especially in fermentation processes, theoretical explanation frequently lags behind technological realisation. Some of the constraints that limit the application of chemical engineering principles are:

1. The reactant mixture is relatively complex. Microbial biomass often increases in parallel with the biochemical transformations it carries out.

2. The bulk densities of suspended microbial cells and substrate particles are generally similar to those of their liquid (usually aqueous) environment and the sizes of the individual microbial cells are relatively small. As a result, relative flow between the dispersed and continuous phases is normally low and it is generally difficult to promote high particle velocities and attain turbulent-flow transfer conditions.

3. Polymeric substrates or metabolites and the mycelial growth of many microorganisms can produce very viscous reaction mixtures which are generally non-Newtonian.

4. The growth mode of some microorganisms, especially of mycelial fungi, can lead to the formation of relatively large multicellular aggregates (clumps or pellets) in which intraparticle diffusional resistances are often serious, leading to partial nutrient starvation or product intoxication.

5. Bioreactors operate under mild conditions compared to those employed in chemical processes, but within those conditions they frequently require critical control of solute concentrations, pH, temperature and local pressures in order to avoid damage or destruction of components essential to the process.
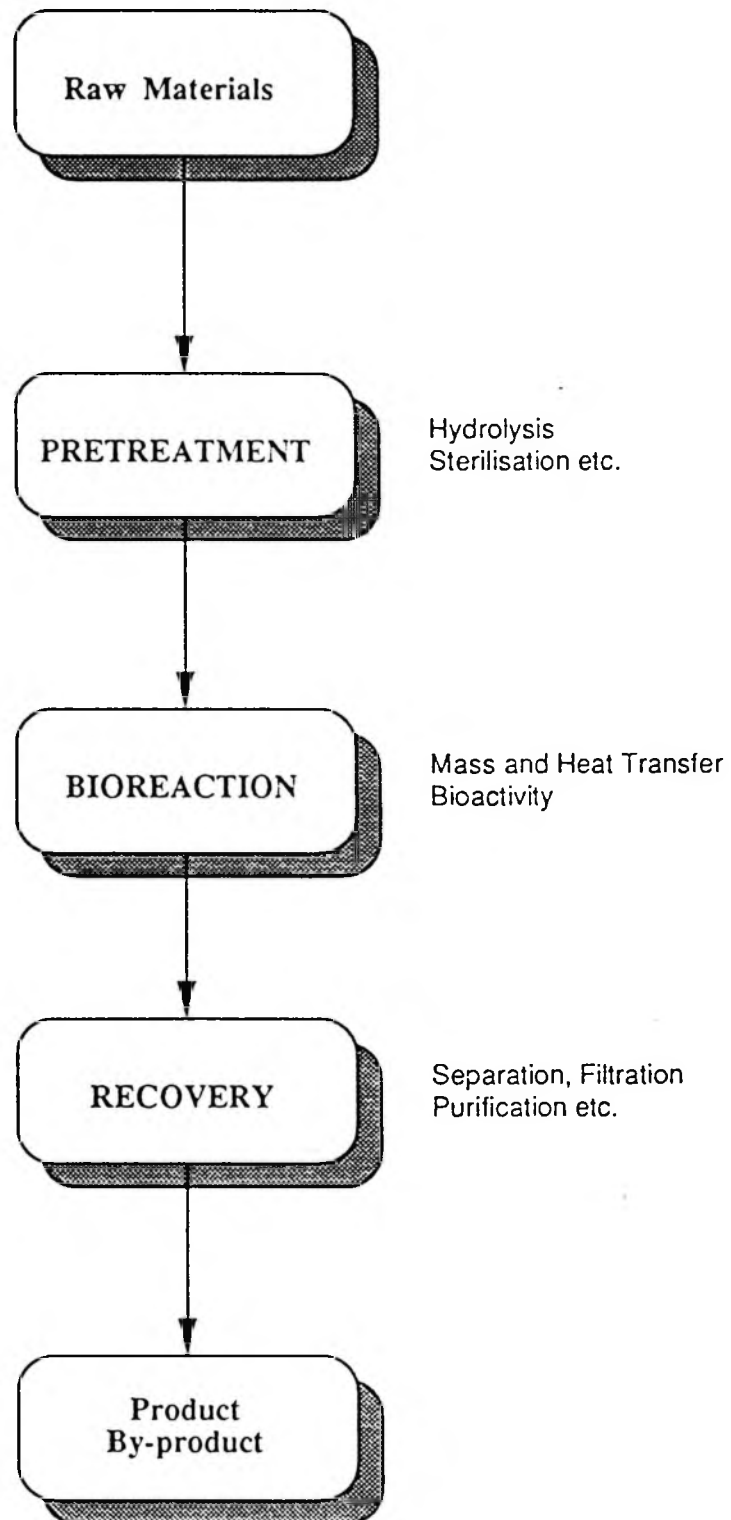
Fig. 1 Generalised Biotechnological Process

6.   Concentrations or reactants and/or products in aqueous media are normally low so that the concentrations driving force for mass transfer are correspondingly limited.

7.   For similar reasons, and because microbial growth rates are substantially lower than chemical reaction rates, relatively large volumes and long residence time are often required.

Bioreactors

Reactors are classified according to whether their contents are homogeneous, in which only one phase is present, or heterogeneous, in which more than one phase is present. Reactors can also be classified as to whether reaction takes place batchwise or continuously, whether they are opened or closed and according to the extent of mixing takes place within the reactor; the idealised extreme types being perfectly mixed and plug-flow reactors.

Choice of the most appropriate type of reactor as well as their efficient design and operation is very important in making successful use of substrates. Several factors should be considered. These include the need for pH and temperature control, the need to supply or remove gaseous reactants, the presence of particulate materials in the feedstock, the chemical and biological stabilities of the substrates and products, the frequency of catalyst replacement, the presence of appreciable substrate and/or product inhibition, the intended scale of operation and the likely uses of the product (Wiseman, 1988) .

For the discussion, reactors are subdivided into two categories, batch and continuous reactors.

Batch reactors

Batch reactors are a versatile and traditional form of reactor. These are basically large stirred tanks into which are placed enzyme (or microorganism) and substrate, the reaction is allowed to occur, the reactor drained and product and enzyme separated.

The *advantages* of batch operation are:

- lower investment cost as not much control is used,
- greater flexibility achieved by using a bioreactor for various products and product specification,
- higher conversion levels as a result of well-defined cultivation period,
- less risk of infection and cell mutation due to relatively short cultivation periods.

The *disadvantages* of batch operation are:

- non-productive idle time for filling, heating, cooling, sterilizing, emptying and cleaning the reactor,
- great stress on measuring instruments due to frequent sterilization,

- higher expenditure due to preparing several subcultures for inoculum,
- high expenses as more personnel needed to control the non-stationary process,
- greater risk to service personnel from possible contact with some pathogenic microorganisms or toxic products.

Hence, batch operations are used when:

- only small amounts of product are involved,
- one reactor is used to produced various products,
- there is a high risk of infection,
- there is a high risk of microorganism mutation,
- product separation from the cultivation medium is discontinuous.
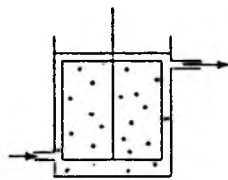
Continuous Flow Reactor

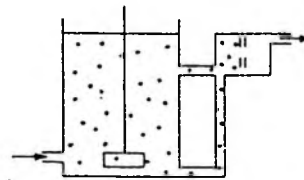Continuous flow reactors are based on the principle of containment of biocatalyst (microorganism) in the
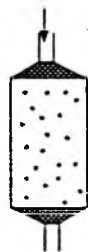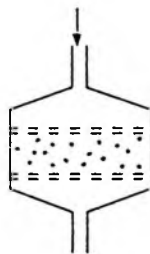
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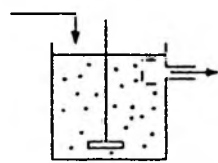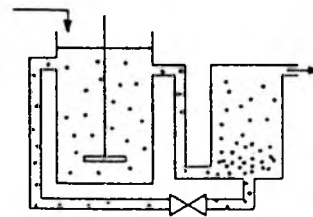
CSTR

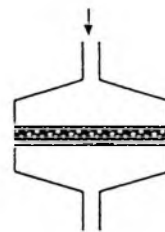CSTR with settling tank

Enzyme attached
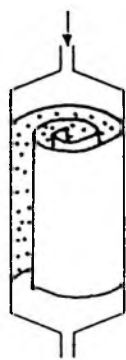to agitator

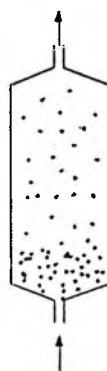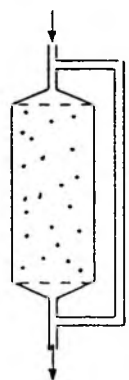CSTR with ultrafiltration

Packed bed reactor

Flat bed reactor

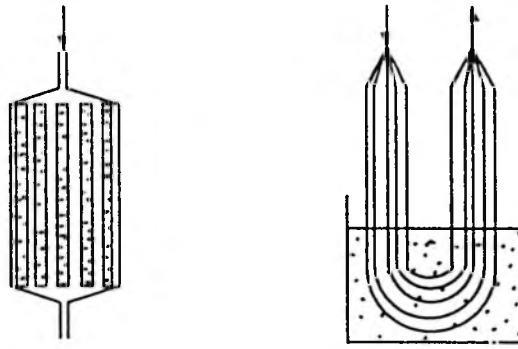Filter bed reactor

Spiral membrane
reactor

Fluidised bed reactor

Recycle reactor

Figure 2 Types of Continuous Flow Reactors

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Hollow fibre reactors

Fig. 2 (Continued)

reactor with the continuous addition of substrate. The medium added may be sterile or it may contain the microorganisms used. The reaction mixture is also drawn continuously from the reactor. All reaction variables and control parameters remain constant in time-steady -state case.

The catalyst can be held in the reactor either by immobilising it in some way or by mixing it uniformly in the fermentation medium with an ultrafiltration unit at the outlet point. Some of these reactors are shown in Fig. 2.

The *advantages* of continuous flow reactor are:

- large scope of mechanisation and automation,
- low wages bill,
- lower reactor volume,
- product quality is constant as operating conditions are invariant,
- less possible danger to service personnel due to improved mechanisation,
- less wear and tear on instruments from sterilisation.

The *disadvantages* of continuous operation are:

- low flexibility as only slight changes are possible,
- raw material quality must be uniform as operating conditions cannot be adapted so easily,
- high investment costs - caused mainly by control and automation equipment,
- continuous renewal of non-soluble, solid substrate can be expensive,
- high risk of infection and microorganism mutation due to long cultivation periods.

Considering all the advantages and disadvantages mentioned above, continuous reactors are preferred for process with high production rates, for gas, liquid or soluble solid substrates and when microorganisms with high mutation stability are involved.

The main types of these reactors are described and their obvious advantages outlined below (Trevan, Boffey, Goulding and Stanburry, 1987; Wiseman, 1988).

Continuous Stirred Tank Reactor (CSTR)

CSTRs consist of an agitated tank to which substrate is supplied at the same rate as the reactor contents are removed. The catalyst (or microorganism) is suspended in the tank through which substrate flows, and is retained within the reactor normally by matching the growth rate of new cells to that of the withdrawal rate, or by filtration, subsequent sedimentation or by being attached to the stirrer paddles.

These reactors are cheap, versatile and especially suitable when liquid phase reactions are being carried out. Supply of gas, and pH and temperature control are easy, fresh catalyst can be easily added to the reactor, and substrates containing particulate materials can be tolerated without causing fouling. However, when oxygen transfer is involved, the relatively high power input required to give efficient agitation in a CSTR is clearly a disadvantage. Furthermore, a non-brittle catalyst is required to prevent attrition by the stirrer blades on the immobilised enzymes.

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In practice the void volume of the reactor is of the order of 98 % (i.e. the catalyst occupies only 1 or 2 % of the volume) which means that compared to packed bed reactors of the same productivity, CTRSs may have to be an order of magnitude larger.

In CSTR the catalyst is homogeneously distributed throughout the reactor at the concentration in the product stream. Thus catalyst concentration is uniformly low, and can never be reduced to near zero. Since good mixing is achieved in CSTR, the biocatalyst will be more prone to product inhibition so that high degrees of conversion will be very difficult to obtain. In practice it is probably uneconomic to aim for conversion factors of more than 90 % with this type of reactor.

CSTRs are commonly used for sewage treatment, single cell protein production (BP and Shell type processes) and alcohol production.

Packed Bed Reactor

These reactors exist in a variety of designs but are all characterised by small size, high productivity even in the presence of product inhibition, low void volume and ease of automation. Packed columns allow a high concentration of biocatalyst to be maintained and are especially suitable when the order of the reaction is greater than zero-order in the limiting substrates.

However, these reactors do have the number of disadvantages. Lack of easy access can make catalyst replacement awkward and environmental (particularly pH) control difficult. Fabrication and commissioning costs are high although running costs may be low. Particulate, colloidal or high viscosity substrate streams tend to block packed bed reactors, and in addition, channeling or blocking of the flow through the catalyst bed may occur. Packed columns are more prone to substrate inhibition than CSTRs, as in the former, the substrate concentration decreases from the input end of the reactor to the output end, while in CSTR uniform mixing ensures that enzyme is exposed to relatively lower average substrate and product concentrations.

To avoid blockage and/or to allow potential gas liberated (e.g. by photosynthetic immobilised plant cells), a sheet of immobilised enzyme rolled up into a spiral and inserted longitudinally into the reactor. Any mixing is dependent upon the flow rate to overcome this problem will reduce productivity and conversion unless either the reactor length is increased or some recycling of the stream is introduced.

Fluidised Bed Reactor

In fluidised beds, the biocatalyst is immobilised onto surfaces of solid support particles and are maintained in suspension relative to each other by the upward passage of substrate and/or gas at high flow rate. Temperature, pH and gas supply are easily controlled using fluidised beds, and substrate containing solid particles can be easily be dealt with. Channeling cannot occur in the beds, mixing is improved and diffusion limitations reduced with the result that high biocatalyst loadings may be used efficiently and productivity of the reactor increased. This reactor will be discussed further in the next chapter.

Hollow Fibre Reactor

These reactors , based upon commercially available ultrafiltration units, where the higher-molecular-weight substrates are separated from the low-molecular -weight products by the semi permeable wall of hollow fibre. They are therefore the most useful for carrying out depolymerisation reactions, especially when using soluble enzymes, so as to ensure good contact with macromolecular substrates. The main disadvantage associated with the use of ultrafiltration reactors are the small sizes of the reactor available, and concentration polarisation, that is blockage of the pores in the membrane by solid, fat or colloid particles present in the substrate.

Conclusion

The importance of bioreactors in this region is very significant because biotechnology is quite a new area of interest and there are a lot of idle resources of organic materials (biomass) especially in our country. Many of these resources if given enough attention will generate useful products (e.g., biogas, fuel, alcohol etc.) and in some cases may help the country to survive in the near future where energy sources will be scarce. The technology of bioreactors has

to be updated among the engineers especially chemical engineers so that the nation can face the next century with little worry for the future generation.

REFERENCES

1. Wiseman, A. (1988), *Principles of Biotechnology*, 2nd ed., Surrey University Press, London.

2. Trevan, M. D., Boffey, S., Goulding, K. H. and Stanburry, P. (1987), *Biotechnology: The Biological Principles*, Open University Press.

3. Bu'lock, J. and Kristiansen, B. (1987), *Basic Biotechnology*, 2nd ed., Surrey University Press, London.

4. Schugerl, K. (1987), *Bioreaction Engineering, Vol. 1*, John Wiley & Sons Ltd., Chichester.