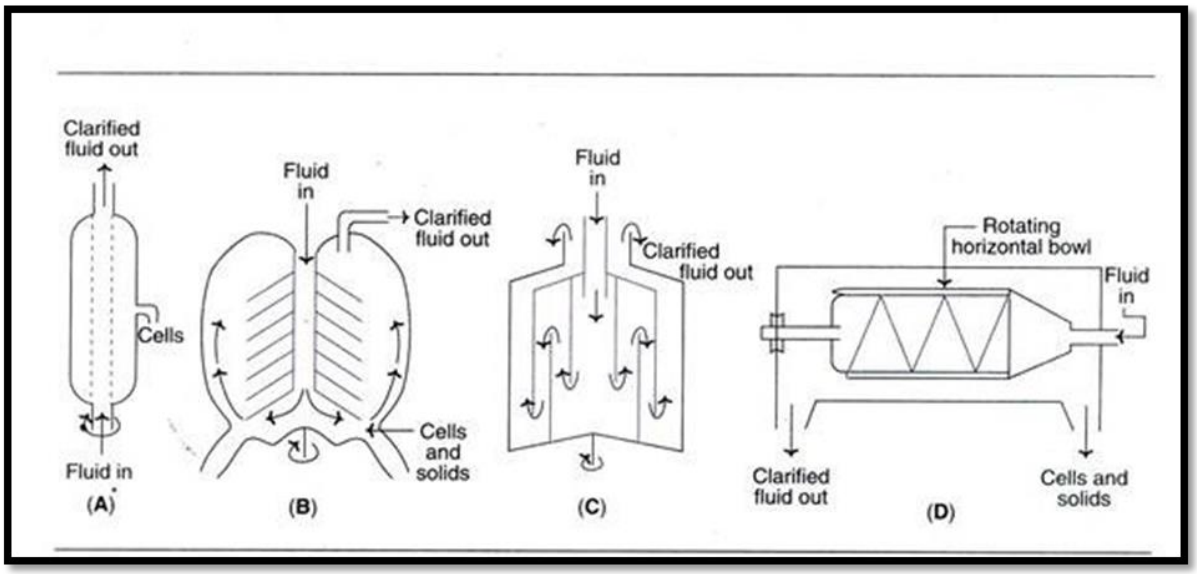
The different types of centrifuges are depicted in Fig. 5, and briefly described hereunder.



Tubular bowl centrifuge (Fig. 5A):

This is a simple and a small centrifuge, commonly used in pilot plants. Tubular bowl centrifuge can be operated at a high centrifugal speed, and can be run in both batch or continuous mode. The solids are removed manually.

Disc centrifuge (Fig. 5B):

It consists of several discs that separate the bowl into settling zones. The feed/slurry is fed through a central tube. The clarified fluid moves upwards while the solids settle at the lower surface.

Multi-chamber centrifuge (Fig. 5C):

This is basically a modification of tubular bowl type of centrifuge. It consists of several chambers connected in such a way that the feed flows in a zigzag fashion. There is a variation in the centrifugal force in different chambers. The force is much higher in the periphery chambers, as a result smallest particles settle down in the outermost chamber.

Scroll centrifuge or decanter (Fig. 5D):

It is composed of a rotating horizontal bowl tapered at one end. The decanter is generally used to concentrate fluids with high solid concentration (biomass content 5-80%). The solids are deposited on the wall of the bowl which can be scrapped and removed from the narrow end.

Spray drying:

- Spray drying is used for drying large volumes of liquids. In spray drying, small droplets of liquid containing the product are passed through a nozzle directing it over a stream of hot gas.
- The water evaporates and the solid particles are left behind.

Freeze-drying:

- Freeze-drying or lyophilization is the most preferred method for drying and formulation of a wide-range of products—pharmaceuticals, foodstuffs, diagnostics, bacteria, viruses. This is mainly because freeze-drying usually does not cause loss of biological activity of the desired product.
- Lyophilization is based on the principle of sublimation of a liquid from a frozen state. In the actual technique, the liquid containing the product is frozen and then dried in a freeze-dryer under vacuum. The vacuum can now be released and the product containing vials can be sealed e.g., penicillin can be freeze dried directly in ampules.

Economics of DSP in Biotechnology

Bio-products include a wide range of chemicals, which may be broadly classified into three major categories on the basis of market volume, market price and requirement of purity, these include

- Very high value and low volume products such as therapeutic proteins and enzymes, factor VIII, interferon, urokinase etc. of very high purity, the volume produced being in the range of grams to kilograms.
- High value, low volume, high purity products such as diagnostic enzymes, human growth hormones, tissue plasminogen activator, monoclonal antibodies and insulin produced in tens of hundreds of kilograms.
- Bulk industrial products relatively of low purity such as organic acids, amino acids, ethanol, antibiotics, proteases and amylases produced in hundreds of kilograms to tons in quantity.

Major bioseparation techniques	Affinity chromatography and preparative electrophoresis	Membrane separation ,adsorption chromatography	Precipitation, filtration, extraction, adsorption

Characteristics of fermentation broth

The characteristics of fermentation broths that influence the downstream processing of biomolecules include

1. Type of microorganisms and their morphological features (size and shape)
2. Concentration of cells, products and their byproducts
3. Physical and rheological characteristics

Morphology of cells

- The cells and cell agglomerates exhibit a variety of shapes. Bacteria and yeast cells occur mostly as homogeneously suspended particles in the fermentation broth.
- Certain strains of bacteria form a slimy mass, which is difficult to separate from the liquid. The viscosity of a liquid also increases due to presence of a slimy mass. The slimy mass may clog and foul the experiment.

Concentration of cells, Products and byproducts

The concentrations of the biomass and that of the products in the fermentation broth are important in deciding on the choice of separation process. The concentrations of biomass as well as that of the products vary widely as shown below.

Biomass	Concentration (% dry weight)	Size (μm)	Bioproduct	Concentration (% dry weight)	Size (μm)
Cell debris	3-6	0.5-2	Alcohols	0.3-0.5	8-12
Bacterial cells	3-6	0.5-3	Organic acids	0.2-0.6	5-10
Yeast	3-6	5-10	Inorganic acids	0.1-0.3	0.1-0.3
Fungi	2-4	10-50	Sugars	0.5-1.0	0.1-0.2
Animal cells	0.02-0.05	10-80	Antibiotics	0.5-1	3-5
Plant cells	0.1-0.5	10-200	Proteins	1-10	0.05-1