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Dear viewers, Namaskar

Welcome to the lecture series on Food technology

Today the topic Fermentor, Design, types and media for fermentors shall be discussed under the following sub headings

1. **Introduction**
2. **Fermentor**
3. **Design of fermentors**
4. **Types of fermentors**
5. **Media for fermentors**

1. Introduction

Fermentation is a widely used process in industry as well as in the production of many foods, beverages, and pharmaceuticals. Ancient fermented foods, such as making bread, wine, cheese, curds, idli, dosa, etc. were produced from the fermentation process. Some commodity chemicals, such as acetic acid, citric acid, and ethanol are made by fermentation.

Fermentation uses microorganisms to convert raw materials to product. Strictly speaking, fermentation is microorganism metabolism on a carbon. Fermentation processes include chemical reactions such as oxidations, reductions, polymerizations, and hydrolysis, as well as biosynthesis and the formation of cells. Some processes may require the presence of air (aerobic), others the absence of air (anaerobic). The rate of fermentation depends on the concentration of microorganisms, cells, cellular components, and enzymes as well as temperature and pH.

Industrial fermentations are typically carried out in large tanks, called fermentors or bioreactor. In view of this, in the present topic we will discuss about what are fermentors, how to design a fermentor and different types of fermentors used in industries with what kind of medium is used to produce the fermented foods or products.

2. Fermentor

A fermentor is a vessel for the growth of microorganisms which, while not permitting contamination, enables the provision of conditions necessary for the maximal production of the desired products. In other words, the fermentor ideally should make it possible to provide the organism growing within it with optimal pH, temperature, oxygen, and other environmental conditions. In the chemical industry, vessels in which reactions take place are called reactors, fermentors are therefore also known as bioreactors.

The first truly large-scale aseptic anaerobic fermentation vessels were developed in the wake of the process developed (during the First World War, 1914-1918) by Weizmann and co-workers of United Kingdom to produce acetone by a deep liquid fermentation using *Clostridium acetobutylicum*.

Fermentors may be liquid, also known as submerged or solid state, also known as surface type. Most fermentors used in industry are of the submerged type, because the submerged fermentor saves space and is more amenable to engineering control and design.

Depending on the purpose, a fermentor can be as small as one liter or up to about 20 liters in laboratory-scale fermentors and range from 1 lakh liters to 5 lakhs liters (approximately 25,000 – 125,000 gallons) for factory or production fermentors. It should be noted that while fermentor size is measured by the total volume, only about 75% of the volume is usually utilized for actual fermentation, the rest being left for foam and exhaust gases.

Basic Functions of a fermentor are as follows:

- It should provide a controlled environment for optimum biomass/product yields.
- It should permit aseptic fermentation for a number of days reliably and dependably, and meet the requirements of containment regulations. Containment involves prevention of escape of viable cells from a fermenter or downstream processing equipment into the environment. These two points are perhaps the most important of all.
- It should provide adequate mixing and aeration for optimum growth and production, without damaging the microorganisms/cells.
- The power consumption should be minimum.
- It should provide easy and dependable temperature control.
- Facility for sampling should be provided.
- It should have a system for monitoring and regulating pH of the fermentation broth.
- Evaporation losses should be as low as possible.
- It should require a minimum of labour in maintenance, cleaning, operating and harvesting operations.
- It should be suitable for a range of fermentation processes. But this range may often be restricted by the containment regulations.
- It should have smooth internal surfaces, and joints should be welded wherever possible.
- The pilot scale and production stage fermenters should have similar geometry to facilitate scale-up.
- It should be contrasted using the cheapest materials that afford satisfactory results.
- There should be adequate service provisions for individual plants.

3. Design of fermentors

There are many requirements that need to be met in the design of a large scale production fermentation facility. The conventional fermentor design was considerably improved during 1940s to accommodate the requirements of strict aseptic conditions, and good agitation and aeration for cultures; for this, steel fermenters with working volumes of 54,000 L were built in United States of America. Modern fermenters are usually integrated with computers for efficient process monitoring, data acquisition, etc.

What should be the basic points of consideration while designing a fermenter?

- Productivity and yield
- Fermenter operability and reliability
- Product purification

- Water management
- Energy requirements
- Waste treatment

In general, a fermentor should provide for the following: (i) agitation (for mixing of cells and medium), (ii) aeration (aerobic fermenters; for O_2 supply), (iii) regulation of factors like temperature, pH, pressure, aeration, nutrient feeding, liquid level, etc., (iv) sterilization and maintenance of sterility, and (v) withdrawal of cells/medium (for continuous fermenters).

Agitation and Aeration: The following components of the fermenter are required for aeration and agitation: (i) agitator (impeller), (ii) stirrer glands and bearings, (iii) baffles, and (iv) sparger (the aeration system).
i. Agitator (Impeller): Agitators are of several different types, e.g., (i) disc turbines, (ii) vaned discs, (iii) open turbines of variable pitch and (iv) propellers. Agitators achieve the following objectives; (a) bulk fluid and gas-phase mixing, (b) air dispersion, (c) oxygen transfer, (d) heat transfer, (e) suspension of solid particles, and (f) maintenance of a uniform environment throughout the vessel.
ii. Stirrer Glands and Bearings: The satisfactory sealing of the stirrer shaft assembly has been one of the most difficult problems; this is very important for maintaining aseptic conditions over long periods. Four basic types of seal assembly have been used in fermenters: (a) the stuffing box (packed- gland seal), (b) the simple bush seal, (c) the mechanical seal and (d) the magnetic drive. Most modern fermenters use mechanical seals; these seals are more expensive, but they are more durable and less prone to leakage or contaminant entry.
iii. Baffles: Baffles are metal strips roughly one-tenth of the vessel diameter and attached radially to the fermenter wall. They are normally used in fermenters having agitators to prevent vortex formation and to improve aeration efficiency. Usually, four baffles are used, but larger fermenters may have 6 or 8 baffles. Extra cooling coils may be attached to baffles to improve cooling.
iv. Sparger: The device used to introduce air into the fermenter broth is called sparger. Spargers are of the following three basic types: (1) porous spargers, (2) orifice spargers and (3) nozzle spargers. In small fermenters, a combined sparger-agitator may be used. In this case, the air is introduced via a hollow agitator shaft, and it comes out through holes drilled in the disc between the blades and connected to the base of the main shaft. This design gives a good aeration in baffled vessels over a range of agitator speeds.

Temperature Regulation: The fermenter must have an adequate provision for temperature control. Both microbial activity and agitation will generate heat. If this heat generates a temperature that is optimum for the fermentation process, then heat removal or addition may not be required. But in most cases, this may not be the case; in all such cases, either additional heating or removal of the excess heat would be required. Temperature control may be considered at laboratory scale, and pilot and production scales.

In laboratory scale fermentations, normally little heat is generated. Therefore, heat has to be added to the system; this can be achieved in the following ways: (a) the fermenter may be placed in thermostatically controlled bath, (b) internal heating coils may be used, (c) water may be circulated through a heating jacket, or (d) a silicone heating jacket may be used.

In case of larger fermenters beyond a certain size, excess heat is generated, and the fermenter surface becomes inadequate for heat removal. The size at which fermenter surface becomes inadequate for heat removal will depend on the fermentation process and the ambient

temperature at which fermentation is being carried out. In such cases, internal coils have to be used to circulate cold water through them for removing the excess heat.

pH control: Certain microorganisms grow in particular pH only. In fermentation it is very essential to control pH in order to grow the desired microorganisms for product formation. pH control sensors are used in fermenter for periodically checking of pH.

Foam Control: Foam is produced during most microbial fermentations. Foaming may occur either due to a medium component, e.g., protein present in the medium, or due to some compound produced by the microorganism. Several compounds have been used as antifoaming agents, and have been found to be suitable for different fermentation processes; these compounds are as follows: alcohols, esters, fatty acids and their derivatives (especially, triglycerides like cottonseed oil, linseed oil, soybean oil, sunflower oil, etc.), silicones, sulphonates, and miscellaneous compounds like oxaline and polypropylene glycol. Antifoams are generally added when foaming occurs during fermentation.

4. Types of fermentors

A variety of fermentors have been described in the literature, but few of them have proved satisfactory for large scale fermentations. Several types of fermentors are known and they may be grouped in several ways: shape or configuration, whether aerated or anaerobic and whether they are batch or continuous. The most commonly used type of fermentor is the Aerated stirred tank batch fermentor. So widely used is this type that unless specifically qualified, the word fermentor usually refers to the Aerated stirred tank batch fermentor.

Fermentors are commonly cylindrical vessels with hemispherical top and/or bottom, are often made of stainless steel and glass and the volume ranging from one litre to several thousand litres. A general description of the following types of fermentor is given in the following sections: (a) stirred tank reactor, (b) airlift fermentor, (c) tower fermentor and (d) bubble up fermentor, (e) single use or disposable fermentor.

Stirred Tank Fermenter: These are glass (smaller capacity vessels) or stainless steel (larger volumes) vessels of 1-1,000 L or even upto 8,000 L. These are closed systems and are usually agitated with motor-driven stirrers with considerable variation in design details, e.g., water jacket in place of heater type temperature control, curved bottom for better mixing at low speeds, mirror internal finishes to reduce cell damage, etc.

Airlift Fermenter: An airlift fermenter consists of a gas light baffled riser tube or draught tube (broth rises through this tube) connected to a down-comer tube (broth flows down through this tube). The riser tube may be placed within the down-comer tube or it may be externally located and connected to the latter . Air/gas mixture is introduced into the base of the riser tube by a sparger. The aerated medium/broth of the riser tube has a lower density, while that in the down-flow tube it is relatively much less aerated and, as a consequence, has a higher density. This density difference drives the circulation of broth. The oxygen is continuously consumed by the cells and carbon dioxide is generated by respiration.

Tower Fermenter: A tower fermenter has been defined by Green-shields and co-workers as an elongated non-mechanically stirred fermenter that has an aspect ratio (height to diameter ratio) of at least 6 : 1 for the tubular section and 10 : 1 overall, and there is a unidirectional flow of gases through the fermenter. There are several different types of tower fermenters,

which are grouped as follows on the basis of their design: (1) bubble columns, (2) vertical-tower beer fermenter and (3) multistage fermenter systems.

Bubble-up Fermenter: It is a bubble column fermenter that is fitted with an internal cooling coil. Air is introduced from the bottom of the column. In this vessel, the cooling coil effectively separates the column into an inner riser/draught tube and the outer down-flow tube. The cooling coil assembly functions as a leaky draught tube. The culture broth rises in the compartment enclosed by the cooling coils and it moves down in the compartment outside the coil, although back- mixing also occurs through the coils. The region above the cooling coil shows good mixing, and there were no poorly oxygenated zones in the vessel.

Single use or disposable fermentor: Recently available single use or disposable fermentor having good productivity compare to classical multiple use bioreactors. Having following advantages.

- Pre sterilized bag, no cleaning or sterilization is needed.
- Powerful and flexible control system.
- All bag contact parts are single use, class 4 tested and ready to use.
- Simplifies validation process.
- 50 to 1000 L working volumes.
- Scalable technology to support increasing volume demand.
- Minimizes investments and maximizes returns.
- Computer assisted programming systems

5. Media for fermentors

Most fermenters require liquid media, often referred to as broth, although some solid-substrate fermentations are operated. In most industrial fermentation processes there are several stages where media are required. They may include several inoculum (starter culture) propagation steps, pilot-scale fermentations and the main production fermentation.

Detailed investigation is needed to establish the most suitable medium for an individual fermentation process, but certain basic requirements must be met by any such medium. All fermentation medium used for the growth and development of microorganisms generally require water, sources of energy, carbon, nitrogen, mineral elements and possibly vitamins plus oxygen if aerobic. On a small scale it is relatively simple to devise a medium containing pure compounds, but the resulting medium, although supporting satisfactory growth, may be unsuitable for use in a large scale process.

On a large scale one must normally use sources of nutrients to create a medium which will meet as many as possible of the following criteria:

- It will produce the maximum yield of product or biomass per gram of substrate used.
- It will produce the maximum concentration of product or biomass.
- It will permit the maximum rate of product formation.
- There will be the minimum yield of undesired products.
- It will be of a consistent quality and be readily available throughout the year.
- It will cause minimal problems during media making and sterilization.
- It will cause minimal problems in other aspects of the production process particularly aeration and agitation, extraction, purification and waste treatment.

A typical fermentation media should contain carbon and nitrogen sources, water, precursors, inducers, elicitors, minerals, growth factors and vitamins.

Commonly used media are as follows:

Molasses: Pure glucose and sucrose are rarely used for industrial scale fermentations, primarily due to cost. Molasses, a by product of cane and beet sugar production, is a cheaper and more usual source of sucrose. This material is the residue remaining after most of the sucrose has been crystallized from the plant extract. It is a dark coloured viscous syrup containing 50–60% (w/v) carbohydrates, primarily sucrose, with 2% (w/v) nitrogenous substances, along with some vitamins and minerals.

Starch and dextrins: These polysaccharides are not as readily utilized as monosaccharides and disaccharides, but can be directly metabolized by amylase-producing microorganisms, particularly filamentous fungi. To allow use in a wider range of fermentations, the starch is usually converted into sugar syrup, containing mostly glucose.

Sulphite waste liquor: Sugar containing wastes derived from the paper pulping industry are primarily used for the cultivation of yeasts. Waste liquors from coniferous trees contain 2–3% (w/v) sugar, which is a mixture of hexoses (80%) and pentoses (20%). Hexoses include glucose, mannose and galactose, whereas the pentose sugars are mostly xylose and arabinose.

Whey: Whey is an aqueous byproduct of the dairy industry. The annual worldwide production is over 80 million tonnes, containing over 1 million tonnes of lactose and 0.2 million tonnes of milk protein. This material is expensive to store and transport. Therefore, lactose concentrates are often prepared for later fermentation by evaporation of the whey, following removal of milk proteins for use as food supplements.

Fats and oils: Hard animal fats that are mostly composed of glycerides of palmitic and stearic acids are rarely used in fermentations. However, plant oils (primarily from cotton seed, linseed, maize, olive, palm, rape seed and soya) and occasionally fish oil, may be used as the primary or supplementary carbon source.

Corn steep liquor: Corn steep liquor is a byproduct of starch extraction from maize and its first use in fermentations was for penicillin production in the 1940s.

However, the use of cane molasses, beet molasses, cereal grains, starch, glucose, sucrose and lactose as carbon sources, and ammonium salts, urea, nitrates, corn steep liquor, soya bean meal, slaughter-house waste and fermentation residues as nitrogen sources, have tended to meet most of the above criteria for production media because they are cheap substrates.

However, other more expensive pure substrates may be chosen if the overall cost of the complete process can be reduced because it is possible to use simpler procedures.

Historically, undefined complex natural materials have been used in fermentation processes because they are much cheaper than pure substrates. However, there is often considerable batch variation because of variable concentrations of the component parts and impurities in natural materials which cause unpredictable biomass and/or product yields. As a consequence

of these variations in composition small yield improvements are difficult to detect. Undefined media often make product recovery and effluent treatment more problematical because not all the components of a complex nutrient source will be consumed by the organism.

Thus, although manufacturers have been reluctant to use defined media components because they are more expensive, pure substrates give more predictable yields from batch to batch and recovery, purification and effluent treatment are much simpler and therefore cheaper. Process improvements are also easier to detect when pure substrates are used.

Conclusion: A fermentor is a specially designed vessel which is built to support the growth of high concentration of microorganisms. It must be so designed that it is able to provide the optimum environments or conditions that will allow supporting the growth of the microorganisms. From the above studies it is observed that various fermentor configurations affect the production rate of fermentation. Various factors like vessel shape, agitation, aeration, baffles, types, media etc. play major role in productivity. There are other so many new novel approaches are developed to increase productivity of spargers, agitators as well as various controlling probes in order to improve productivity of bioreactor. There is no fermentor which can satisfy all the conditions but availability of disposable fermentor may contribute to increase productivity as well as ease of fermentation process.