Chapter 11
Modernization of Fermenters for Large-Scale Production in the Food and Beverage Industry

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Abstract Fermentation is an inexpensive and low-energy method of conserving decomposable unprocessed materials. Many foods have microbial sources or include components generated by fermentation using microorganisms. This procedure is helpful for extending the usability of food and drinks, as well as improving the health benefits of products. This chapter examines the modern aspects of food and beverage fermentation in large-scale fermenters. Descriptions of fermenters and their underlying technology are provided for each case to demonstrate the link between the equipment and the process. Engineering characteristics are reported for bioreactor scale-up, including important problems in the scaling and exploitation of bioreactors. Agitation in bioreactors is also discussed. Some aspects associated with bioreactor/fermenter design when computer simulation is used are reported. Finally, the technology of modern bioreactor types is presented.

Keywords Fermentation · Microorganism · Scaling up · Bioreactor · Food · Beverage · Technology

Introduction

Fermenting is a biotechnological unit operation involving microbes. Through fermenting, raw sustainable substrates are changed to added-value products, such as fermented beverages and food, enzymes, alcohols, acids, and others. The production of commercial fermented products has improved from focused genetic

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engineering methods that created modern microbial strains (Campbell-Platt 1994). The development of end or subsidiary products is reliant on the selected microbial variety and ecological conditions, such as bioreactor type. For an ideal fermenting procedure, the microbe variety should be chosen and created in light of the desired end product. Information on the biochemical modifications of matured foods can help producers to control their results by modifying varieties and conditions. In addition to development conditions, media, strains, and fermenting methods influence outcomes and hence profitability. Fed-batch, continuous, and batch fermentation systems can be selected for high efficiency. Continuous and fed-batch systems can handle substrate restriction amid fermentation procedures. Higher efficiency also can be achieved by the immobilization of cells, which can be derived incrementally from the biomass collection in the bioreactor, leading to an expanded assembly of biocatalysts in the bioreactor.

Modern large-scale fermentation procedures can vary throughout the beverage and food industry. The focal point of these procedures are generally bioreactors, which can be categorized by the bioreactor feeding operation (continuous, fed-batch, or batch), fixation of the biocatalyst, stirring system of the bioreactor (hydraulic, pneumatic, or mechanical agitation), and the accessibility of oxygen (anaerobic, microaerobic, or aerobic), among others. The choice of bioreactor or fermentation technique for a specific application should consider the advantages and inconveniences of every setup. This decision should include the properties and accessibility of essential crude materials, any important venture and working costs, manageability, accessibility of a skilled workforce, and the desired efficiency and quantifiable profit (Inui et al. 2010). In large-scale applications, every fermentation technique needs to run effectively and dependably; thus, a significant aspect in the choice of a fermentation/bioreactor procedure is the capital expenses per unit of item recuperated. However, even with a plan and effective operation, issues with the subsidiary product and wastewater administration are unavoidable in large-scale operations.

This chapter is focuses on the aspects of fermenters in food manufacturing, biotechnological approaches, and the modernization and design of bioreactors in the industry.

Modern Fermenters for Food and Beverages

Beer Fermenter Technology

Fermenter for Lager Beers

Worldwide, most beer is manufactured using a variety of lager *Saccharomyces carlsbergensis* yeast, which has a tendency drift away from the base of the fermentation vessel. Thus, the tanks used for the fermentation of lager beer—which are the most well-known and critical in brewing—should take into consideration this yeast property.

Fig. 11.1 Fermentation
and lagering tank
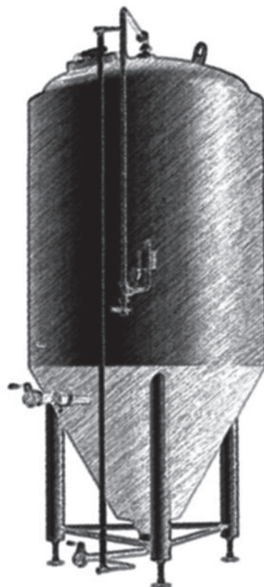
A noteworthy achievement in fermenter configuration was the implementation of closed fermenters. Leopold Nathan patented his plans for cylindrical tanks, which were vertical with funnel-shaped bases, in 1908 and 1927. Modern versions of the Nathan tank are now the most used fermenters. The size of these tanks range from 100 to 6000 hL. An important attribute of these tanks is their well-defined cone at the bottom. An inclination of 70° is necessary for the yeast to subside into the bottom of the tank toward the end of fermentation (Fig. 11.1). This design allows most of the yeast to be isolated, resulting in a relatively yeast-free lager. In a few designs, improvements and storage can occur in one tank from fermentation, without centrifugation of the brew during transfer to another tank for development. A number of advantages have been noted for cylindroconical tanks compared with round or open square fermenters (Briggs et al. 2004), including a reduction in capital expenses of 25–35%, a reduction in operating expenses of 50–65%, reduction of product losses, expanded vessel usage, less introduction of bitter compounds, reduced space requirements, and potential for the collection of CO_2.

Lager fermenters are generally three to four times shorter in their diameter than the height and use an operation pressure of 1–1.5 bar. European fermentation tanks for lager beer commonly use shorter tanks with a diameter-to-height ratio of <2:1, which causes fermentation to equalize more completely than in horizontal vessels. In taller tanks with a proportion of >3:1, there is an tendency for increased generation of more alcohol to the detriment of esters. Expanding the dimensions of the tank can decrease the expenses per unit volume; doubling the dimensions of the tank results in a cost increment of approximately 35% (Briggs et al. 2004).

Fig. 11.2 Stainless steel
fermenter tank

Cylindroconical tanks cannot be completely filled for fermentation. A substantial volume of froth is created by the advancement of CO_2, which can cause the pressure discharge valves to clog. Initially, fermentation tanks for lager beer were steel with a glass or epoxy tar lining. However, this coating must be regularly inspected to ensure its integrity. Furthermore, mellow steel is inclined to rust; thus, present-day wtanks are typically made of stainless steel using chrome-nickel (Fig. 11.2). Usually, 304 stainless is used; however, V2A steel is not completely impervious to chloride particles or to pH <4.5. This is not typically an issue for fermenters when solutions with an elevated chloride substance 316 can be determined; however, it is significantly costlier than 304 steels.

The fermenter should be outfitted with a cooling attribute to release the heat created during fermentation and to enable required temperature control. The tanks are filled and exhausted from the bottom, which decreases oxygen entrance. Pipes are fitted to the tanks for the addition of wort, evacuation of yeast, and expulsion of lager. There are also pressure and vacuum alleviation systems. In most of today's tank, the vessels used a pipe-work system. The valves are therefore either associated with each tank or gathered into a "valve routing block" to which each tank is associated; the valves are either manually or remotely controlled. Fermenters also need protection. Outside tanks should be protected against the elements, which may differ significantly depending on geographical location. Indoor vessels also need some protection to minimize the need for system temperature control.

Ale Beer Fermenters

Because lager brews are the most common type of beer worldwide, most technological advancements in fermentation have been associated with cylindroconical tanks. However, in the United Kingdom and Ireland, stouts and ales are

Fig. 11.3   Square tank for wheat beer fermentation

the customary beers. These brews are regularly created with top fermenting yeast varieties, similar to some German and Belgian ales. Conventional ale fermentation uses an open solitary tank to ease yeast expulsion, such as Yorkshire vessels (Anon 2008).

Square tanks (Fig. 11.3) from Yorkshire were initially manufactured with stone and slate, with a size up to 50 hL. However, today's Yorkshire squares are almost always manufactured with stainless steel (304) and have capacities up to 850 hL to accommodate the production needs of a modern brewhouse. Yorkshire squares have a lower section that is isolated from the exposed upper part by a slightly slanting deck. Underneath is a progression of channels known as organ funnels, and perhaps a few sewer vents with spines around the edge. On the highest point of the deck, there is an outlet with an embedded attachment to help remove the yeast.

Vinegar Fermentation Tanks

The word *vinegar* comes from the French *vin aigre* ("harsh wine"). The total ethanol concentration (%v/v) and acetic acid concentration (%w/v)—termed the global concentration (GK)—needs to be consistent throughout acetification. The GK yield is the remaining vinegar, indicated as a level of the GK toward the beginning of acetification. There are various factors affecting acetification, including the oxygen, alcohol, and microbes (Hutkins 2006; Adams 1985; Hills 2014). Wine is normally fermented in tanks, although barrels may be used in some cases, especially for white wine. Generally, wine was historically manufactured in simple, solid, nonmetallic, mineral-matter containers called *lagars*, in which the grapes would be crushed. Lagars are still used occasionally in Portugal by a few winemakers.

Fig. 11.4 Frings acetator technology

In the culture strategies for vinegar, microorganisms form a film at the surface between the air and acidifying environment; this appears to be a straightforward process, yet it may experience varying levels of complexity. The fast process of obtaining vinegar is due to the speed of acetification, which can be increased by expanding the area of dynamic microbial film and enhancing oxygen exchange to the acidifying stock. The acidic microorganisms develop as a film on an inactive material pressed into a false-bottomed tank. The acidifying stock is splashed onto the inert material surface and streams down in opposition to the counter-current flow of air. The inert material in which the microbes are packed is typically composed of a lignocellulosic substance, such as sugarcane bagasse, wood fleece, or vine twigs; however, different substances, such as coke, have also been used. The acetic acid stock begins in a marsh at the tank base and reflows up to the point where the desired level of acidity is attained. A quicker reaction rate indicates that the wash was heated during entry via the bed; thus, on the span of the fermenter, some chilling might be required. The procedure is completed in a semi-continuous system to maintain a high acidity level throughout the process, with a large portion of the biomass held inside the bed.

A commonly used fast vinegar procedure, with a controlled temperature and constrained air circulation, will typically acidify a vinegar stock with a GK value of 10 and an underlying ethanol percentage of 3% in 4–5 days. The quickest acetification rates are accomplished by submerged acidification, in which acetification microbes are suspended in a environment that is oxygenated by air sparging. The most powerful commercial system is the Frings Acetator (Fig. 11.4), which uses a self-preparing aerator to achieve extremely efficient oxygen exchange.

To quickly and efficiently submerge a culture, a semi-continuous operation regularly takes 24–48 h. However, this operation requires much more oversight than

what is required for simpler methods. The acetification organisms are very vulnerable to air supply interruptions. To survive suspended in a pH environment of 2.5 and an acidity of 10–14%, the microbes require a consistent provision of energy from air. An air supply interruption of just 1 min in a stock with a GK value of 11.35 can completely and permanently halt acetification; that is, the acetification will not continue when air circulation resumes.

Fermenters in Winemaking

Inox tanks started to gain widespread acceptance in the late 1970s. The advantages of this material include ease of cleaning and the capacity to operate in cooling techniques. Two levels of inox have been used in the manufacturing of fermenters. Grade 304 is most suitable for the fermentation of red wine. The superior grade 316, which contains molybdenum, is stronger and more resistant to erosion; this grade is suitable for both white and red wines. The top of inox tanks may be either open or shut, with a fermentation lock. Variable limit tanks are likewise possible and are helpful, even when the tanks are only halfway filled. These tanks have a drifting metal top, held up by an inflatable plastic tire at the edge. Fiberglass tanks are also occasionally used as a less expensive option to inox. In the early twentieth century, many produced replaced their wooden tanks with inox; however, wood is again gaining interest as a material for tank development at some small- and medium-sized wineries. The most common vessels of winemakers are stainless steel and cylindrical (Fig. 11.5) with an inner cover. The cover is held in situ by an expansive

Fig. 11.5 Wine fermenter tank

vinyl cap, allow the top to be safe at any height in the vessel. Most vats have a level base with a low port on one depleting side. These vats should be put on a stand or depleted using gravity. A few models have three legs welded in situ; these vats also usually have a cone-molded base with an additional deplete port in the middle. Some larger tanks have a built-in stainless-steel coat or belt connected over the center for cooling. A glycol cooling unit may be linked to ports on the coat when chilling is desired. Normally, these vessels are costlier than vessels without a chilling coat. The stainless-steel material is exceptionally chemically inactive and completely safe for beverages. Cleaning is simple with the top evacuated. The cover of a variable limit tank has a port that is suitable for a maturation bolt; thus, these vessels can be used as open or shut fermenters.

The fermentation of red wine uses the whole grape. When manufacturing red wine, two facts should be considered. First, during fermentation, yeast generate CO_2 gas and alcohol. As the CO_2 rises into and out of the wine, a portion gets caught in the peels and causes them to float on the wine surface in a mass named "the cap." The cap rises over the surface of the liquid, which causes the must volume to extend in the vessel. Thus, when charging red wine fermentation tanks, one should select a fermenter that it is somewhat larger than the desired final volume of wine. The skins in the "top" should be washed with the fluid wine a few times each day during fermentation. For large volumes, this can be achieved using a procedure called a "pump-over."

White wines are manufactured using only the grape juice. The maceration and detachment of the juice from the solids occurs before the start of fermentation. Because there are no solids, there is no compelling reason to punch the top. However, white wines are exceptionally touchy to oxygen introduction, so a mechanism to restrict oxygen intake is desirable. Consequently, open-top fermenters are not used. Sealed fermenters are the best choice for making white wines.

Bread Proofers

To guarantee reliable outcomes and maintain production schedules, specific equipment may be used to control the speed and characteristics of fermentation in breadmaking. A proofer of dough (also referred to as a proofing oven or box) is a heating chamber used as a part of baking to promote the yeast fermentation of dough through moderate temperatures and managed humidity. Warmer temperatures increase yeast activity, resulting in increased CO_2 creation and a higher, quicker rise of the dough. Dough is usually allowed to rise in the proofer prior to baking, but it can also be used for the principal rise or mass fermentation. Proofer temperatures can range from 70 °F (21 °C) up to 115 °F (46 °C). Bakers often use large temperature- and humidity-managed proofers.

A dough retarder (Fig. 11.6) is a chiller used to self-manage the yeast fermentation while proofing a mixture. Decreasing the dough temperature creates a steady, slow rise with other maturation characteristics, resulting in more elaborate flavors.

Fig. 11.6 Stainless steel automatic dough retarder proofer

In sourdough bread production, chilling declines the wild yeast activity of the Lactobacilli (Gänzle et al. 1998), which creates flavoring from acetic and lactic acid, for example. Sourdough that is chilled prior to baking may have greater sourness. To prevent the batter from drying, a wind stream is maintained in the mixture retarder. Industrial bakers frequently chill the dough at approximately 50 °F (10 °C).

A banneton is a kind of wicker bin used to give structure to molded chunks of bread during sealing. A banneton wicker bin is also called a brotform or proofing bushel. It is regularly used for dough that is too delicate or soft to keep up its shape while rising. The bread is ordinarily removed from these crates prior to baking. Traditionally, these bushels are made from wicker; however, some new proofing crates have been manufactured using rattan, cane, spruce pulp, terracotta, and polypropylene. A banneton sometimes has a material liner (usually cloth) to keep the mixture from adhering to the sides of the container. However, with use, bannetons usually become non-stick because a small amount of flour collects in them. These wicker containers are used both to give shape to the dough and to draw off humidity from the outside layer. Bannetons are available in elliptical or round shapes.

Dairy Product Fermentation

Lactic acid bacteria play an important role in the creation of fermented milk products. They can ferment lactose and produce lactic acid, which decreases the milk pH (Tamime 2008; Park 2009). As a consequence, the pH attains the isoelectric point of the protein (casein), which is the main protein in milk. At that point, the positive and negative charges are in equilibrium. The casein then coagulates and coagulum

appears (Tamime 2008; Park 2009; Clark et al. 2009). This causes both biochemical and physical transmutations in the item. When integrated with lactic acid, starter yeasts may produce organic molecules, such as acetaldehyde, ethanol, acetic acid, diacetyl, and exopolysaccharides, which affect the consistency and flavor profiles of the product (Clark et al. 2009; Hutkins 2006). Thus, variants of cultures and production conditions can cause different characteristics for these products.

Cheesemaking Mechanization

Mechanization and automation have been implemented for the large-scale manufacture of cheese. Huge industrial units stocking a few million kilograms of milk each day. The fat-to-casein ratio for cheese can be achieved via mechanized methods. Cheese can be manufactured in mechanized tanks in which the filling process is controlled using a computer. Culture expansion, cutting, cooking, stirring, renneting, and discharging operations also can be automated (Fig. 11.7). Encased double-jacketed tanks are available with mechanical stirring and cutting instruments. The mixing and cutting tools turn on a pole horizontally or vertically with adjustable speed. Computerized cheesemaking processes and the ability to control pH inline also help to reduce labor costs. Numerous tanks are available with a mechanized gel-quality analyzer to systematize the cutting stage. Whey and curd division can be executed on a depleting conveyer. In a cheddaring tower, air pressure and vacuum

Fig. 11.7 Coagulation vat

pressure can be used for the curd pressing, which is salted and processed in a mellowing/salting transporter. This salted curd can be squeezed and shaped into 18-kg pieces in a piece former, followed by automated packing and transportation to the aging room (Chandan 2014).

Yogurt Fermenters

Large amounts of yogurt can be delivered in a series of individual cupboards. This procedure can be mechanized for continuous production through a tunnel organization. However, the idea of continuous yogurt manufacturing is novel. Pallets with pots of yogurt can be set on a conveyor or smooth rollers and pass through a tunnel composed of two areas. Hot air is circled in the tunnel hatching portion. The pallet rate is determined by the rate of the transport line, which in turn is managed by the speed of lactic acid generation in the drain. Toward the completion of the fermentation time, which is proportionate to pH 4.5, the pallets pass through the cooling segment so that the warm air is supplanted by the introduction of cool air. The yogurt is halfway cooled in this area; the final cooling happens in the chill store. Because the yogurt is moving during the hatching/cooling stages, great care should be taken to prevent harm to the coagulum.

An update to the tunnel organization has been described in the literature (Bylund 1995). The loaded containers of the inoculated milk are put in open-plan cartons and separated from each other. The goal is that the coursing warm/chill air in the brooding and chilling stages can reach each individual container and provide precise temperature control (Fig. 11.8). At the point when the predetermined ideal pH (normally 4.5) is achieved, the time has come to begin cooling. The crates (pallets) are motionless during brooding. They are put in the hatching part of the tunnel to discourage handling.

Through differentiation, the coagulum of mixed yogurt is created in mass. The structure of the gel is destroyed earlier or during the chilling and bundling stages. Nevertheless, preparing the drain base for the production of blended yogurt is as depicted previously. The types of fermentation vats used in factories for the creation of blended yogurt include the following:
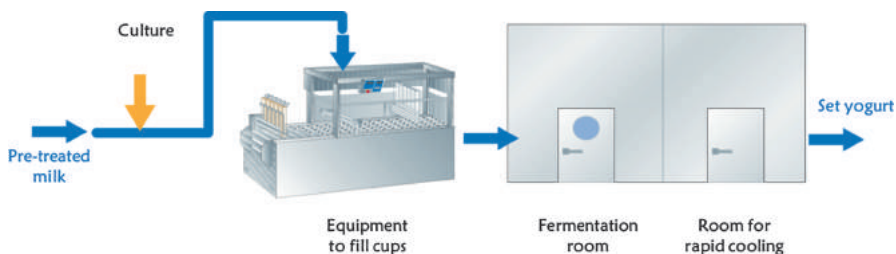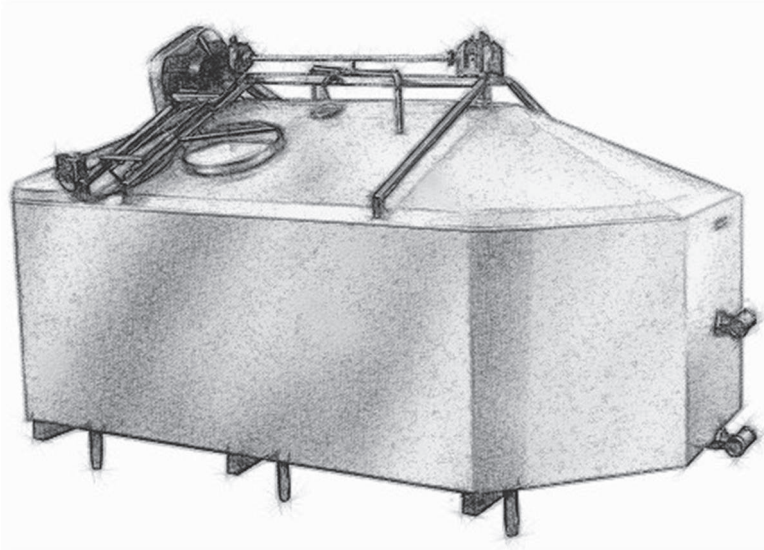

Fig. 11.8 Production of set yogurt

Fig. 11.9 Yogurt coagulation vats

- *Flexible tanks:* A flexible tank is assigned as a number duty vat, with one dedicated to milk fermentation. It is a water-jacketed tank in which vapor can be used during the warming stage; circulating chilled water is used to cool the drain to 40–45 °C. The temperature is kept at 42 °C during the fermentation stage. Finally, chilled water is used to cool the yogurt.
- *Fermentation tanks:* Fermentation tanks are protected, as the end goal is to maintain an even temperature during the hatching stage. The stirring technique in such vats is unforced (Fig. 11.9) because the cone-shaped base encourages simple expulsion of the coagulum (see Fig. 11.9).
- *Chilling/fermentation tanks:* Chilling/fermentation tanks are water jacketed. Hot water (40–45 °C) is circulated during the brooding stage, followed by cold water for incomplete cooling of the coagulum.
- *Sterile fermentation tanks:* Sterile fermentation tanks are modified versions of ordinary fermentation vessels. These vats are utilized for the manufacture of yogurt under germ-free conditions. The vat is protected and suitable for use with a pH electrode and thermometer. The air penetrating and leaving the tank is separated. The essential goal of an aseptic aging tank is to limit contamination of the yogurt with molds and yeast. A sterile tank is always pressurized with germ-free air; a similar approach is used for the generation of mass starters with an aseptic tank.

For protection, each tank is furnished with an additional pipe for air, as well as a security system to keep the vat from exploding from the vacuum created by the drop-in temperature in the wake of cleaning. All of the above vats have a froth-diminishing inlet fitting that mitigates the issue of foam generation in the vat.

Furthermore, most of today's yogurt fermentation vats are fitted with a pH meter to monitor lactic acid generation by the starter (Watanabe et al. 2008; Corrieu et al. 2005; Mulchandani et al. 1995).

Meat Fermenters and Fermentation Technology

The filling of frankfurters takes place in computer-regulated cooling chambers, where they are left to mature for development and improvement of microbes. A typical chamber is shown in Fig. 11.10. Humidity, temperature, and air velocity should be carefully managed to control microbial development and catalyst activity.

Meat maturation technology differs between the United States and Europe. High maturation temperatures (35–40 °C) are common for U.S. frankfurters, followed by a gentle warming procedure as a sort of pasteurization, rather than drying. Hence, cultures such as *Pediococcusacidilactici* or Lactobacillus plantarum, which develop well, are commonly used. In Europe, different technologies might be used, depending on the area and atmosphere. There is a trend to produce short-handled, smoked wieners in chilly and muggy countries (e.g., northern Europe), whereas a prolonged process for dried hotdogs is common in drier and hotter nations (e.g., Mediterranean region).

In northern European countries, frankfurters are aged for around 3 days at transitional temperatures (25–30 °C), followed by a short maturation duration (about

Fig. 11.10 Maturation chamber

3 weeks). These frankfurters are put through a fast drop of pH and are generally smoked for a particular taste (Eva et al. 1997; Demeyer and Stahnke 2002). Mediterranean wieners require a longer duration of preparation. Maturation occurs at moderate temperatures (18–24 °C) for around 4 days, followedd by mellow drying for a more extended time, generally months. *L. curvatus* or *L. sakei* are most frequently used as starters (Toldrá et al. 2001, 2014; Toldrá 2008, 2010). The duration needed for the aging step depends on the temperature and type of microorganisms used.

The process is very different in China and other Asian nations, where frankfurters are first dried at 48 °C for 36 h and afterward at 20 °C for 3 days. Aging is moderately poor; the harsh taste, which is viewed as undesirable, is thus lessened. Chinese crude sausage is eaten in the wake of warming (Leistner 1992).

Vegetable Fermentation Containers

Not all receptacle materials are suitable for maturation. Aging happens in acidic, salty conditions. Metal, aside from high-grade commercial stainless steel, can pit and debase; thus, it is generally not used. Ceramic vessels and plastic receptacles are more stable. Regardless of material, the selected food receptacle should be simple to wash and without profound abrasions, pits, or fragments that can provide a refuge for unsafe microorganisms or influence the aging. Wooden vessels are used to age vegetables; however, they can be challenging to keep intact and sterile. Vessels and other gear should be cleansed in hot, foamy water before use. Chlorine should not be used to clean the equipment because the remaining chloramine and chlorine deposits on the container could affect the development of maturing microbes. If chlorine is used, the equipment should be washed again to eliminate any lingering chemicals.

Ceramic vessels are available in different shapes and sizes. When selecting a container, both the shape and size should be considered. For food safety and adequate maturation, it is vital to have the saline solution/juices at a level of 1–2 in. over the aged vegetables. Such a vegetable plunge allows the items to remain without oxygen, which supports the development of lactic acid microorganisms and other maturing life forms. Keeping the vegetables immersed accounts for the salt to plaster the item, which additionally promotes the development of lactic organisms. Thus, it is critical to select a maturing crock that allows the vegetables to be totally immersed under the saltwater liquid. The style of vessel does not influence the vegetables' security but could influence quality. It is vital to cover the items for both quality and safety.

Plastic vessels also can be used effectively to ferment vegetables, particularly polyethylene vessels with high density (HDPE-2 plastic) that are free of bisphenol and phthalate. These chemicals have been introduced to a few plastics to increase their adaptability; however, they can affect human health, especially for children.

Fig. 11.11 Glass container for anaerobic fermentation of vegetables

Glass vessels (Fig. 11.11) may be used. However, care must be taken to ensure they are not chipped, broken, or split. Quart canning jugs may be used. However, spoilage could be an issue because it can be harder to keep vegetables immersed.

Engineering Aspects for Bioreactor Scale-up

Fundamental Problems in the Design and Operation of Bioreactors

An efficient bioreactor regulates, encloses, and controls a biological reaction. To achieve this, a chemical technician should take account of two items. The first is the appropriate reactor factors for the specified physical, biological, and chemical system. A macro-kinetic (chemical) system embraces microorganism excrescence and matter manufacture. Microorganisms will embrace bacterium, fungi, yeast, and fish, plant, animal, and bug cells, as well as other biological matter. The opposite space of dominant significance in a bioreactor design affects the bioreaction factors, such as restrained temperature, optimum pH, adequate substratum (conventionally a source of carbon; essentially fats, proteins, and sugars), water accessibility, salts as nutrients, vitamins, gas, evolution of gas, and removal of byproducts.

Ideally, a bioreactor should be planned to promote the best physiology of the microorganism, eliminate or reduce pollution from undesirable microbes, and prevent changes to the microorganism. This section provides an outline and summary of bioreaction techniques, the benefits and downsides of a variety of system types, and their everyday applications. A number of subtopics are beyond the scope of this

chapter, including biology, sterilization, heat transfer, rheology, mixing, fluidiza-
tion, surface phenomena, mass transfer and transport enhancements, hydrokinetics,
instrumentation, and method management.

Agitation in Bioreactors

The stirring mode within a bioreactor produces the fluid movement that allows
many alternative tasks to be achieved. A typical agitated bioreactor is shown in
Fig. 11.8. Important features to understand include the interactions between the
liquid movement, the agitator momentum, and the power input devoted to the bio-
reactor and these assignments. In addition, it is necessary to understand how a
change to the scale affects these relationships. Several of these aspects are often
studied before a bioprocess has been selected; these physical features are most per-
tinent to microorganism fermentations. The characteristics that are specific to the
organism are developed and can sometimes diverge for each case. The features that
are more relevant for scale-up are discussed later. The physical aspects have been
discussed elsewhere for conditions significant to an extensive variety of life forms
(Gupta and Ibrahim 2013; Laskin et al. 2011; Nienow et al. 1997, 2010, 2011;
Doran 2013).

   This section explores the significance of microbial maturations for which the
thickness does not substantially exceed that of water, such as microscopic organ-
isms and yeast. Thus, sticky polysaccharide and filamentous frameworks are
excluded from this discussion. With such low thickness, the stream in the bioreactor
is turbulent from a 5-L bench bioreactor to the largest scale. That is, the Reynolds
number can be calculated as $R_e = \left(\rho_L N D^2 / \mu \right) > \sim 10^4$, where R_e is the development
medium thickness (kg/m^3), ρ_L is its consistency (Pa s), D is the impeller length (m),
and N is its speed (rev/s). For scale-up, because the stream is turbulent, the substan-
tial estimation of the Reynolds number does not make a difference. Turbulent stream
speculations can be used to examine the fluid mechanics in the bioreactors over the
scales.

   The movement of oxygen in a fermentation broth has been investigated since the
1940s when "submerged fermentations" were first used. The subject was revisited
recently (Laskin et al. 2011; Al-Rubeai 2015; Pangarkar 2015). The general oxygen
request of the cells throughout the batch or fed-batch fermentation should be met by
the oxygen exchange rate and the request increments as long as the quantity of cells
is expanding. Generally, for each mole of O_2 used, 1 mol of CO_2 is created (Pangarkar
2015). Subsequently, an extremely high oxygen exchange rate must be achievable.
This rate relies upon the mass exchange coefficient, $k_L a$(1/s), and the driving force
for mass exchange, ΔC, because

$$\text{OUR} = k_L a \times \Delta C \tag{11.1}$$

Estimations of $k_L a$ provide essential data about a bioprocess or bioreactor. These calculations indicate that handling conditions provide a sufficient supply of oxygen for the expansion of cells. Likewise, $k_L a$ can be utilized to optimize control factors over the lifecycle of a bioprocess. That optimization would be founded on the oxygen request at different points in time and the development period of the organic matters. Barometers for optimization could include item yield, power utilization, or preparation time.

The oxygen exchange rate of a bioreactor is emphatically affected by the hydrodynamic conditions being utilized as part of the bioprocess (Fig. 11.8). These conditions are a component of energy scattering, which relies on the working conditions, physicochemical characteristics of a culture, geometrical variables of the bioreactor, and the attendance of oxygen-devouring cells.

During cell culture, oxygen is exchanged from a gas (commonly an air pocket or headspace) to a fluid, so it can eventually be ingested into a cell and expended. In the most straightforward terms, this procedure can be depicted as the flux over a hindrance layer communicated as a result of the driving force and mass transport coefficient ($k_L a$) in Eq. 11.2:

$$J^0 = k_G \times (p_G - p_i) = k_L \times (C_i - C_L) \tag{11.2}$$

In that condition, J^0 is the oxygen molar flux (mol/m²s) by the means of the gas–liquid network, k_G and k_L are the neighborhood mass-exchange coefficients, p_G is the oxygen halfway weight in the gas stage, and C_L is the broken-down oxygen fixation in the fluid. Index i alludes to values in the gas–liquid network.

Because interfacial focuses are not straightforwardly quantifiable, it is normal to consider a unique instance of Eq. 11.1 that portrays flux under or at harmony:

$$J^0 = k_G \times (p_G - p^*) = k_L \times (C^* - C_L) \tag{11.3}$$

In Eq. 11.3, p^* is the oxygen weight in balance with the fluid stage, C^* is the oxygen immersion in the mass fluid, and K_G and k_L are the general mass-exchange coefficients. In any case, when the dissolvability of oxygen in water is low and most mass exchange resistance is on the fluid side of the interface, the general mass-exchange coefficient can be thought to be equivalent to the neighborhood coefficient ($K_L = k_L$). Accordingly, the oxygen mass exchange rate per unit of reactor volume (dCO_2/dt) is acquired by duplicating the general flux of the gas–liquid interfacial range per unit fluid volume using Eq. 11.4:

$$\frac{dCO_2}{dt} = k_L a \times (C^* - C_L) \tag{11.4}$$

The mass adjustment for the dispersed oxygen in the very blended fluid stage is portrayed in Eq. 11.5:

$$\frac{dC}{dt} = OTR - OUR \tag{11.5}$$

Here, dC/dt is the amassing oxygen rate in the fluid stage, OTR is the oxygen exchange rate from gas to fluid, and OUR is the oxygen take-up rate of the microorganisms. The last term can be calculated by multiplying $qO_2 \times CX$, where qO_2 is the specific oxygen take-up rate of the microorganism utilized and CX is the biomass fixation.

Without biomass or with non-respiring cells, biochemical responses do not occur and $OUR = 0$. For this situation, Eq. 11.5 can be disentangled as follows:

$$\frac{dC}{dt} = k_L a \times \left(C^* - C_L\right) \tag{11.6}$$

Because it is difficult to measure k_L and a independently, the item $k_L a$ is treated as a solitary quantifiable variable: the volumetric mass-exchange coefficient. Assurance of $k_L a$ is accomplished by recording the framework reaction following a change of the harmony oxygen fixation.

Integrating the outflow of the past condition yields Eq. 11.5:

$$\ln\frac{\left(C^* - C_2\right)}{\left(C^* - C_1\right)} = k_L a \times \left(t_2 - t_1\right) \tag{11.7}$$

Here, C_1 is the convergence of oxygen at time t_1. For example, in a framework that focuses on dispersed oxygen with an underlying estimation of 0, this equation progresses toward becoming an instance that declines the broken-down oxygen fixation:

$$\ln\left(1 - \frac{C_L}{C^*}\right) = -k_L a \times t \tag{11.8}$$

For the case of an issue that decreases the dispersed oxygen fixation, the equation moves toward becoming

$$\ln\left(\frac{C_{L0}}{C_L}\right) = k_L a \times t \tag{11.9}$$

Here, $k_L a$ is affected by numerous factors. Variables incorporate everything from a bioreactor's size and configuration to the sparging of gas, blending, cell line, media sort, temperature, pH, salt substance, and antifoaming specialists (2). When one of those elements changes, the elements of the bioprocess, including $k_L a$, also change. Given such a broad weakness, it is not surprising that genuine in-preparation $k_L a$ estimation has been constrained. Researchers have depended to a large degree

on the implicit usefulness of the bioprocesser to maintain an appropriate oxygen stream rate.

Because k_La estimations include checking levels of dispersed oxygen following a framework issue, the outcomes can be affected by the reaction time (or speed) of a sensor making those judgments. Sensors with reaction times ($\bar{\tau}r$) on the request of the main demand time steady of the mass-exchange ($1/k_La$) require careful treatment of their information to account for the time delays in readings reported by the oxygen sensor.

For the impact of this effect to be negligible, a general guideline is that the sensor's reaction time must be less than one-tenth of the time required for mass exchange. If a sensor's reaction time does not meet this prerequisite, the information must be treated with Eq. 11.10:

$$C_{me}(t) = C^* + \frac{C^* - C_0}{1 - \tau_r k_L a}\left[\tau_r k_L a e^{\frac{-t}{\tau_r}} - e^{(-k_L a)}\right] \tag{11.10}$$

in which $C_{me}(t)$ is the deliberate estimation of oxygen at time t. That condition cannot be linearized, so the nonlinear fitting of the observed reaction information is required to estimate k_La.

The estimation of k_La is interesting for both the size and setup of a reactor vessel. Although some observationally inferred articulations have been defined for k_La in non-Newtonian liquids, there is not an endless supply of conditions that can influence the outcomes. Similarly, anticipating k_La is impractical, and k_La estimations should be performed only for bioreactors.

The estimation of k_La rate constants can be calculated for any reactor vessel, from a shaker carafe to the most advanced single-use bioreactor. However, the applicability of k_La to a wide range of elements likewise changes the most ideal approach to quantify it. Correspondingly, distinctions in dispensable bioreactor development and working technique indicate a need to change the general guidelines for k_La estimation. This is not very troublesome, but rather is essentially an impression of contrasts in bioreactors.

The estimation of k_La is similar for both O_2 exchange from the air to the broth and CO_2 from it. For oxygen exchange, the driving force is the distinction between the oxygen focus around the bubbles and that in the broth, which should be held over the basic dO_2 throughout the fermenter for the duration of the procedure. Likewise, the dCO_2 must be stored underneath, which will prompt a decrease in fermentation rate or efficiency.

In low-thickness frameworks, it has been reported (Pangarkar 2015) that k_La is subject to only two parameters: the aggregate mean specific energy dissemination rate forced on the framework, $\left(\overline{\varepsilon_T}\right)_g$ (W/kg) and the shallow air speed vs (m/s), which is equal to (vvm/60) (volume of broth) / (X – the sectional area of the bioreactor). $\left(\overline{\varepsilon_T}\right)_g$ and v_S should together be adequate to deliver the vital k_La, where

$$k_L a = A \left(\overline{\varepsilon_T} \right)_g^{\alpha} \left(v_S \right)^{\beta} \qquad (11.11)$$

This equation is independent of the impeller type and scale, and α and β are generally approximately 0.5 ± 0.1 regardless of the fluid. However, A is largely dependent on the development medium characteristics (Pangarkar 2015; Kroschwitz 2007). An expansion of antifoam that decreases $k_L a$ or salts that increase $k_L a$ may prompt a 20 overlay distinction in $k_L a$ for similar estimations of $\left(\overline{\varepsilon_T} \right)$ and v_s. Regular estimations of $\left(\overline{\varepsilon_T} \right)$ are approximately 5 W/kg. For the air flow rate, there is approximately 1 volume of air for each volume of development medium (vvm). Because the estimation of $k_L a$ is comparable for both O_2 and CO_2 exchange, if scale-up is implemented at a steady vvm (or near it), the driving force for the movement of O_2 in and CO_2 out will remain basically consistent over the scales. In this scenario, because vvm scales with the fermenter volume and vs scales with its cross-sectional zone, vs is incremental. There is some deliberation about whether $\left(\overline{\varepsilon_T} \right)_g$ should incorporate the influence of the sparged air ($\approx vsg$, where g is the acceleration from gravity, 9.81 m²/s), which becomes significant on scale-up at steady vvm. This approach should also solve issues with high dCO_2 on scale-up (Nienow 2006).

Modernization of Fermenters Using Computer Simulations

The scale-up of bioreactors is necessary to increase the amount and efficiency of manufacturing. However, the design, development, and assessment of bioreactors for large-scale production are expensive and time-consuming. Some basic restricting variables include fluid mechanics, such as incomplete mixing, supplement and oxygen circulation, and mass exchange. The yield of biomolecules in an aerobic bioreactor shifts significantly with general oxygen mass exchange ($K_L a$). To increase the yield of bioreactor operations, it is common to increase oxygen admission. However, this expanding gas stream rate also causes issues. First, it causes extreme shear force on biomolecules and cells, possibly harming them (although evidence for this in the literature is sparse). Second, extreme oxygen promotes frothing, which influences reaction volumes and thus affects efficiency. A bioreactor's operations and its surroundings are frequently determined by exploratory work, which is costly and delays production. (Biomolecular yields also rely upon biology and biochemistry; however, these topics are outside the scope of this chapter.)

Computational liquid dynamics (CLD) can be used to recreate and optimize blending, gas hold-up and mass exchange coefficients, and the dispersion of gasses inside bioreactors. Also, CLD can be used to simulate upstream operation steps, such as cleaning-in-place exercises, sanitization cycles, and the area and rates for including food, buffers, and nutrients. CLD can help to improve a bioreactor procedure by evaluating shear stresses, stream fields, and mass-exchange qualities. Downstream procedures, such as the scale-up of columns for chromatography, can

be determined using CLD. This section concentrates on the hydrodynamic and blending impacts during the scale-up of bioreactors and combined multiphase liquid-gas hydrodynamics, as well as the transfer of oxygen in conveying and mixed tank bioreactors.

Impact of Mixing

Almost all bioreactors used in industry are mixed tank reactors that include liquid blending. Vessel arrangements and impellers can affect item quality, yield, and purity. Often, a blended tank configuration results in incomplete blending. Examinations with CLD and blending speculations can provide insight into bioreactor scale-up. CLD can demonstrate blending impacts, including a forecast of mix times, control numbers, turbulence amounts, and shear amounts. CLD also tells the time-history of turbulence and shear amounts accomplished by cells in a bioreactor. These insights can be a important component for scaling-up bioreactors alongside the customary tip-speed rules or power numbers. For example, during scale-up or downsizing investigations, these forecasts can help to determine impeller rpm speeds, types, and locations. Most organizations lack the adaptability to change impellers or purchase new gear, so they must select the correct reactor vessel from the available reactors inside the facility. CLD expectations can be regularly reviewed with ease through small-scale tests, such as downsize runs. Because the fundamental principles do not vary with scale, these models can apply over different scales (Wittmann et al. 2017; Paul et al. 2004; Baltz et al. 2010).

Mass Transfer Liquid-Gas Impact

In large-scale aerobic bioreactors, oxygen is typically a constraining component because of its low dissolvability into culture media. Dispersed oxygen concentrations are required to meet basic oxygen requests by microorganisms (Flickinger 2013; McDuffie 2013; Nielsen et al. 2012). The rate of air decreases below a dispersed oxygen concentration of 0.005–0.02 mM/L for most life forms. This should be unsurprising over a range of scales that can span four levels of magnitude between laboratory research and production levels. In mammalian cell-culture bioreactors, CO_2 generation and outcome mass exchange are also of importance.

The modelling perspective portrayed here for oxygen exchange is sufficiently general to be applied when investigating CO_2 development. The mixing consistency is basic for oxygen circulation in a bioreactor; however, different variables affecting mass exchange include bubble size dispersion, dispersed oxygen concentration, and liquid pressure. Bubble size determines the accessible interfacial ranges for liquid-gas mass exchange and is influenced by parameters such as turbulence, shear rate, and buoyancy. Bubbles disperse and join together due to their associations with

turbulent swirls, which provides conveyance for a range of bubble sizes. When bioreactors are scaled up from the research laboratory to production size, their design must meet both oxygen conveyance and oxygen mass exchange requirements. Therefore, a precise predication of bubble size conveyance is required to determine the stream attributes and interfacial zones for heat and mass exchange computations (Nielsen et al. 2012; McDuffie 2013).

Planning

A bioreactor outline and scale-up comprehension can be increased through orderly modelling trials that start with blending investigations using CLD and blending speculations. In an organized display approach, blending can be considered and later consolidated with multiphase stream flow using bubble connections and size distribution to foresee gas–liquid mass exchange. A summary of approaches to address foreseeable oxygen exchange for bioreactors is presented here, with testing approval for two contextual analyses. An arrangement of a populace adjustment equation for bubble number thickness is combined with CLD estimations to anticipate bubble measure distribution. For the two cases considered here, the gas hold-up and fluid volumetric mass exchange coefficients were both observed to be in complete concurrence with trial results. The advantages of an appropriate plan include monitoring hazards during scale-up and decreasing downtime.

Configuration of Fermentation Vessels

This section explores the engineering applications and aspects of a range of fermentation technologies, as well as the advantages and drawbacks of the individual technologies. The fermentation techniques discussed here include surface/tray, trickle-bed setups, continuous, air-lift loop, batch, submerged, and semi-continuous. As mentioned previously, almost all of the technologies have broad applicability.

Fermentation in Batch Bioreactors

Many fermentations are batch-wise (Fig. 11.12). A batch fermenter with a stirred system is an upright, closed, tube-shaped vat with baffles connected to the wall, a water coat or heating/cooling convolution, a gadget for persuasive air circulation (called a sparger), a mechanical stirrer that generally has two or more impellers, a way to introduce nutrients and organisms, a way to collect samples, and outlets for releasing gasses. Today's fermenters are often computerized and generally have methods for constantly observing, recording, or controlling pH, oxidation/reduction

Fig. 11.12 Batch reactor diagram
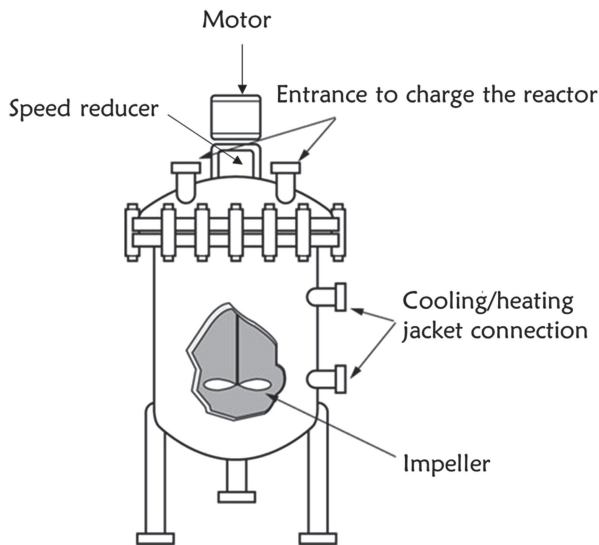
potential, dissolved oxygen, CO_2 and O_2 effluent, and fermentation compounds. However, a fermenter without all of these gadgets can still be operated manually.

The primary part of batch fermentation is usually sterilization. Then, the disinfected medium is injected with microbes that were selected to attain a particular outcome. Throughout a vigorous reaction, cells, substratum, vitamins, nutrient salts, and aggregations of the item fluctuate with time. The correct admixture maintains the variations in characteristics and temperature at satisfactory levels. To achieve aerobic growth, the environment is aerated to produce a never-ending flow of a chemical element. Frothy byproducts (similar to CO_2) are removed, and gas-shifting and aeration procedures occur virtually ceaselessly. An alkali or acid is intercalary if the pH scale must be governed. To maintain adequate frothing levels, antifoaming agents may also be intercalary if required by a foam-sensing element.

A large chrome-steel batch bioreactor for manufacturing beer is shown in Fig. 11.1. (A batch bioreactor is analogous to the fermenter showed in Fig. 11.3, although without the reprocess loop.) One of the main types of batch systems is the receptacle bioreactor, which is used for economical aerobic bioreactions for items such as acids and antibiotics. In this system, the plates are filled with the medium as well as the microbes; furthermore, the airflow gives rise to the fermentation, during which the exhalation gas is released (Najafpour 2006; Cinar et al. 2003). Once the fermentation is complete, the final result is far from the plates. Thus, this technique is ineffective for manufacturing large commercial quantities. It drops rapidly to the edge and exposes the immersing tank systems, which are planned to hold considerably higher capacities.

Generally, batch fermentation systems have a variety of benefits, including the following: smaller risk of poisoning or cell change, because of a comparatively transient extension amount; less capital risk than continual procedures for a similar

fermenter volume; additional adaptability for a variety of objects and biotic systems; and greater product transformation levels because of confidence in the development quantity (Cinar et al. 2003). The drawbacks include the following: lower efficiency levels because of the time required for cooling, sterilizing, heating, filling, evacuating, and cleaning the fermenter; multiple target instrumentations because of the recurring need for sterilization; greater cost associated with the need for many subcultures for immunization; higher prices for task and/or method management because the method is not continuous; and the risks associated with large-scale industrial sanitation, such as possible contact with unhealthy microbes or toxins. Typical implementation problems for batch fermenters include the following: a need to create the item with a reduced risk of pollution or microbe mutation; operations in which only very small quantities of items are created; a method that utilizes one reactor to create a variety of products; and techniques during in semi-continuous or batch item break-up is suitable.

Tubular Fermenters

The tube-shaped fermenter received its name because it looks like a tube. Tubular fermenters are usually continuous unperturbed fermenters in which the reactants progress in a predictable route. Reactants enter from one side and evacuate from the other side, with no stirring. Because of the lack of stirring, there is a progressive reduction in the concentration of substrate between the inlet point and the outlet; at the same time, the product expands similarly.

Fermentation in Continuous Bioreactors

A continuous mixed fermenter is basically like a batch fermenter, with a difference in the inlet and outlet media. An explanation of the attributes of continuous fermentation is very involved. A culture environment, which is either aseptic or contains microbes, is constantly added into the fermenter to maintain a consistent state (Chen 2013; El-Mansi et al. 2011). The product is also removed constantly from the fermenter. Reaction factors and constraint factors are stable, allowing for a consistent state inside the fermenter (El-Mansi et al. 2011). The outcome is continuous profitability and yield.

This setup has a number of potential advantages, including the following: expanded possibility for procedure automatization; lower task cost because of robotization; reduced unprofitable time associate with purging, filling, and sanitizing the reactor; reliable item quality because of consistent operating conditions; reduced danger to staff because of mechanization; and decreased stress on equipment from sanitizing. The disadvantages of continuous fermenters include the following: limited adaptability, even when only slight varieties in the procedure are

needed (e.g., throughput, environment, oxygen temperature, fixation); obligatory consistency of crude materials to guarantee that the procedure remains continuous; larger capital investment in the charge and mechanization of the vessel; greater costs for the continuous sanitation of the environment; higher operating costs with the nonstop recharging of insoluble, strong substratum, such as straw; and greater danger of tainting and cell transformation because of the moderately short development timeframe. A continuous bioreaction is sometimes used for procedures with high-volume generation; techniques using gas, fluid, or dissolvable substrates; and methods including microbes with high change dependability. Typical finished products include vinegar, processed wastewater, and baker's yeast.

## Fermentation Using Semi-continuous Bioreactors

Semi-continuous bioreactors use a hybrid method of continuous and batch functioning in a variety of procedures. Most commonly, the fermentation begins in a batch system, until the development-restricting substrate has taken over (Lim and Shin 2013; El-Mansi et al. 2011). At that point, the substratum is bolstered to the fermenter as indicated (batch) or is maintained by an increased culture time (continuous). For auxiliary metabolite generation, in which cell development and item creation regularly happen in distinct stages, the substrate is usually included at a predefined rate. Like batch fermenters, semi-continuous fermenters do not stop operating.

This setup has a number of advantages, including the following: increase yield, resulting from a very defined development period during which no cells are added or removed; more opportunities to optimize the environmental conditions of the microbes concerning the period of development or generation and maturation of the culture; and almost stationary functioning, which is vital for transforming organisms and those at risk for tainting (El-Mansi et al. 2011). The disadvantages include the following: lower efficiency levels because of the time-consuming need for filling, warming, sanitizing, cooling, discharging, and cleaning the fermenter; greater labor costs; and potentially powerful process control requirements for the procedure. Semi-continuous fermenters are typically used when continuous techniques are not feasible, such as when slight transformation or pollution of the organism occurs. These fermenters are also used when batch techniques do not provide the desired efficiency levels.

Mixed Tank: Submerged Bioreactors

The most well-known oxygen-consuming bioreactor being used today is the mixed tank reactor (El-Mansi et al. 2011; Saxena 2015; Inamdar 2012). Ideal for large-scale implementations, this bioreactor requires low capital and has low task expenses. For research center investigations with small volumes, the stirring vessel

Fig. 11.13 Stirred
tank – submerged
bioreactors
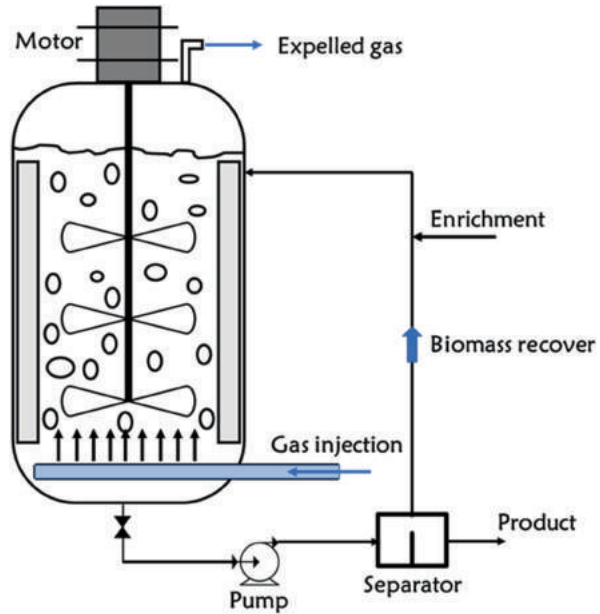
is normally contained in glass. A stainless-steel vessel is used for large-scale (industrial) implementations. The height-to-diameter ratio of the vessel can vary based on the evacuation requirements.

The operating standards of a mixed tank bioreactor are generally basic. As shown in Fig. 11.13, the inoculum and clean medium is brought into a disinfected tank, and the air injection regularly infiltrates at the base. For ideal stirring, the tank highlights an instigator system as well as confounds, which have a whirlpool effect that could obstruct legitimate stirring. In the beginning of the procedure, warm water may be passed through the baffles to warm up the equipment; afterward, cold water could be circled within them to protect against overheating. The number of baffles commonly ranges from 4 to 8. As the fermentation advances, the bubbles delivered by the air injection are isolated by the fermenter as they progress upward.

A variety of fermenters are currently in use. The most widely recognized is the four-bladed circle turbine. More modern designs have 12 or 18 sharp edges, or sunken ones, which seem to enhance the hydrodynamics. At the highest point of the tank, gas fumes are released and the item streams down, where it is removed from the tank. In a constant-stream mixed tank reactor, the substrate is continuously sustained in the framework and the item is consistently removed and isolated, with the substrate returned once again into the tank for reuse. Likewise, with uniform chemical reactors, bioreactors can be used in parallel or series with controlled reuse streams.

Fig. 11.14 Airlift
bioreactor
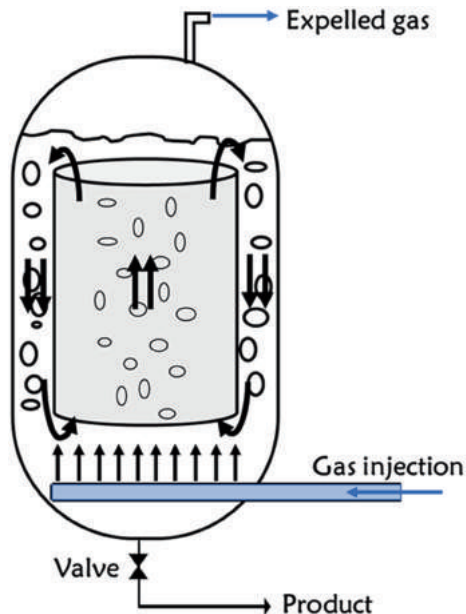
Airlift Reactor Equipment

In an airlift reactor (also called a tower reactor), the bubble column includes an assembly conduit (Saxena 2015). Various airlift reactors are being used today. Air is commonly sent via an irrigator into the base of a median draft tube, which guides the flow of air and the milieu (Fig. 11.14). Gas goes up the tube, shaping bubbles, and gas fumes separates at the highest point of the section. Degassed fluid then descends, and the item is depleted from the tank. The tube is intended to act as an interior heat exchanger; otherwise, a heat exchanger could be attached to an inward flow loop (Saxena 2015).

The airlift approach has a few benefits over other customary bioreactors, such as the classical fermenter. For example, it has a straightforward design with no moving parts or fermenter shaft seals, which requires less maintenance, has less danger of deformities, and needs less demanding sanitation. Furthermore, it has a smaller shear rate for more prominent adaptability, the ability to be used to develop both animal and plant cells; effective gas-stage withdrawal; a substantial and defined interfacial contact zone with less energy input; a highly controlled stream and productive stirring; well-characterized residence time for all stages; expanded mass-exchange because of the improved oxygen solvency accomplished in extensive tanks with more noteworthy pressures; the possibility for large-volume tanks and thus expanded yield; and greater heat release compared with customary mixed tanks.

    The fundamental weaknesses of this approach include the following: higher start-up capital investments because of the large-scale procedures; more prominent air throughput and high pressures required, especially for large-scale operation; limited abrasion with an ideal pressure driven diameter for the ascender and downcomer; limited productivity of gas pressure; great difficulty in maintaining steady levels of substratum, supplements, and oxygen with the microbes circling through the bioreactor and states transforming; and wasteful gas/fluid detachment while frothing occurs. However, these disadvantages can and should be controlled for when planning airlift frameworks. For example, if just a single area serves as the sustain source, the microbe would encounter endless cycles of high development followed by starvation; this would cause undesirable results, low yields, and high death rates. A design with numerous sustain points would eliminate this hazard, particularly for large-scale operations. Similar dangers are found with a solitary passage point for oxygen; oxygen should be transmitted at different places inside the vessel, with most of the air entering at the base to circle the liquid through the reactor.

External-Loop Airlift Reactors

Another kind of airlift technology is the airlift external-loop reactor system (AELR), which is generally used for a batch system. The AELR illustrates a different perspective, where the downcomer and vessel are actually higher than they

Fig. 11.15 External-loop airlift bioreactor
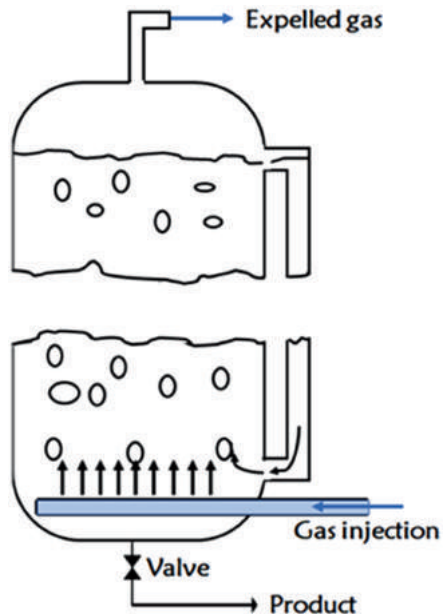
appear for the specific extended diameter (Fig. 11.15). As a variation of the airlift technique, the AELR uses a prompted course to coordinate air and fluid throughout the vessel. This approach comprises a riser and an outer downcomer, which are associated with the base and the top, respectively (Saxena 2015). As infused air at the base of the riser makes gas bubbles that start to ascend through the principal tank, gas fumes separate at the top; the subsequent dense solution drops through the downcomer.

The AELR has a few advantages over the classic airlift technique, including the following: effectual heat exchange and productive temperature control; a small abrasion with an ideal pressure-driven width for both the downcomer and riser; a highly defined time for the individual segments of the AELR; an expanded open door for estimation and control in the riser and the downcomer; and free control of the gas input-rate and fluid speed by a throttling gadget in the riser and downcomer.

Fluidized Bed Fermenters

Fluidized bed fermenters are similar to tube-shaped fermenters. In both continuous mixed fermenters and tube-shaped fermenters, there is a genuine threat of the microorganisms being drained. The fluidized bed reactor addresses this issue as a hybrid of the mixed tank and tubular tank setups. The organisms in a fluidized bed fermenter are maintained in suspension by a circulating rate whose power adjusts to gravity. If the movement was smaller, the bed would stay settled. If the circulating rate was at a higher speed than the mass of the organisms, elutriation would occur, with the organisms being drained from the fermenter.

Anaerobic Bioreactions

Anaerobic bioreactions occur within a number of setups, such as ethanol creation, winemaking, lager blending, and wastewater treatment. Advances have been reported for wine, ethanol, and lager creation due to product changes and decreased assembly costs. Consistent bioreactors have been marketed for brewing, but group fermenters continue to receive capital investments. Waste treatment is a field that has developed because of very useful innovations in setup; however, not as much consideration has been given to creating more modern wastewater treatment systems.

Conclusion

Today, fermentation operations are under pressure from demands for changes to product ranges and the scale of manufacturing. This can be ascribed to a variety of factors, including large-scale bioprocesses and improved fermentation techniques, which have prompted the advancement of new fermented foods. To drive these procedures—both new and old—a comprehensive understanding of food fermentation is required. Policymaking has also played a part in hastening improvements within this industry. For example, modern policies have expanded research and development investments for new equipment designs, and in addition to guiding the directions, standards, and licensed innovations that address the issues resulting from increased production. Thus, this chapter presented an outline of various aspects of modern bioreactors and innovations in the industry. The nutritional status of fermented foods can likewise be enhanced by the informed selection of maturing organisms with respect to the human diet and gastrointestinal microbiota. In this regard, fermented food could be viewed as an augmentation of food absorption and aging procedures; thus, it could be designed to provide valuable benefits to human health and well-being. Another planned technique to increase the metabolic efficiency of bioprocesses is the use of appropriately controlled ultrasonication, which can be used at the biocatalyst level (cells and catalysts) to improve their capacity and sonobioreactor execution.

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