FERMENTATION TECHNOLOGY

Abstract

Fermentation is a complex process that involves molecular oxidation or reduction mechanisms driven by selective microorganisms under anaerobic conditions. This transformative process results in the production of various bioactive molecules, which offer significant health benefits. The fundamental principle of fermentation technology entails cultivating organisms under ideal conditions, providing them with essential raw materials like carbon, nitrogen, salts, trace elements, and vitamins.

The primary function of fermentation lies in the conversion of NADH back into the coenzyme NAD+, allowing it to be utilized again in glycolysis. During fermentation, an organic electron acceptor (e.g., pyruvate or acetaldehyde) interacts with NADH to produce NAD+, yielding by products such as carbon dioxide and ethanol (as seen in ethanol fermentation) or lactate (in lactic acid fermentation).

The metabolically derived end products, formed over the life span of microorganisms, are released into the surrounding medium. These products are then extracted for various human applications, holding significant commercial value. Based on the specific end product generated, fermentation can be categorized into four types: lactic acid fermentation, alcohol fermentation, acetic acid fermentation, and butyric acid fermentation.

To facilitate the fermentation process, a fermenter or bioreactor is employed. This device is designed for the cultivation of microorganisms and

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contains all the necessary components for the large-scale synthesis of various compounds, including antibiotics, enzymes, and beverages across different industries. The microorganisms within the fermented are cultivated in a manner that maximizes the yield of the product while minimizing the required resources.

Keywords: Fermentation, biochemical, metabolically, microorganisms.

I. INTRODUCTION

Fermentation is a complex biochemical process that encompasses the various activities of organisms throughout their life cycle, including growth, development, reproduction, and eventual demise. Fermentation technology leverages the use of microorganisms and enzymes to manufacture compounds at an industrial scale, which have widespread applications in the food, pharmaceutical, and alcoholic beverage industries.

Biotechnology represents the convergence of natural sciences and engineering methodologies, utilizing cells and living systems to drive industrial production and service delivery. It serves as a bridge between the biological and engineering realms, facilitating the large-scale production of valuable substances and services. Therefore, fermentation is a biotechnological device which achieves the production of several industrial products by the use of microorganisms. Biotechnology in convergence with fermentation technology brings about improved products like hormones, enzymes, antibiotics and other metabolites. The basic principle of fermentation is to obtain energy from carbohydrates at an anaerobic condition. In glycolysis, glucose gets partially oxidized to pyruvate and it is then converted into acid or alcohol, NAD+ is regenerated and it participates in glycolysis to generate more ATP. Fermentation is able to produce only 5% of the energy produced by aerobic respiration. The fundamental idea behind industrial fermentation technology is that organisms are cultivated in the right environments by supplying raw materials that satisfy all the requirements, including those for carbon, nitrogen, salts, vitamins, and trace elements.

The study of fermentation dates back to the mid-19th century when Louis Pasteur conducted pioneering research in this field. The significance of fermentation was further recognized when Eduard Buchner received the Nobel Prize in 1907 for his demonstration of fermentation in yeast cells. Subsequently, in 1929, scientists Arthur Harden and Hans Euler-Chelpin were honored with the Nobel Prize for their investigations into the enzymes responsible for fermentation. The 1940s marked a crucial turning point with the establishment of antibiotic production through fermentation techniques.

British scientist Chaim Weizmann played a pivotal role in developing fermenters for acetone production. However, it wasn't until 1944 that large-scale fermenters were designed for yeast production. Finally, in India, in 1950, Hindustan Antibiotics Ltd. in Pimpri, Pune, achieved a significant milestone by developing an industrial-scale fermenter that boasted aseptic conditions, effective agitation, and aeration capabilities.

II. THE PROCESS OF FERMENTATION

Microorganisms depend on carbohydrates as a source of energy and sustenance. This vital energy is distributed to every component of a cell as required, primarily through organic compounds such as ATP (adenosine triphosphate). In the presence of oxygen, aerobic respiration is initiated, commencing with glycolysis, a process that transforms glucose into pyruvic acid. However, when oxygen is lacking, anaerobic conditions give rise to fermentation, resulting in the generation of various organic molecules, such as lactic acid, which facilitates ATP production. It is worth noting that aerobic respiration relies on pyruvic acid. The ability to transition between these two distinct modes of energy production is

contingent upon the specific environmental conditions and the characteristics of individual cells and microorganisms.

Throughout the fermentation process, these advantageous microorganisms, including yeasts, molds, and bacteria, engage in the breakdown of sugars and starches, ultimately yielding alcohols and acids. This not only enhances the nutritional value of the food but also serves as a natural preservation method, extending the shelf life and preventing spoilage. Additionally, the products of fermentation offer essential digestive enzymes, and fermentation itself contributes to the pre-digestion of the food. In this process, the microbes utilize sugars and starches as their source of nourishment, initiating the breakdown of the food even prior to consumption.

III. TYPES OF FERMENTERS

The different types of fermenters used extensively in Industries are

1. **Continuous Stirred Tank Fermentor:** It creates a uniform setting conducive to cell growth and multiplication while effectively maintaining temperature control. The mechanical agitation involved may generate shear stress that could potentially impact the cultured cells. This challenge can be mitigated by altering the configuration and size of the impeller blade or by introducing substances like bovine serum albumin or dextran. Additionally, the issue of foaming can be addressed by incorporating antifoaming agents. The primary focus for desired end products remains the cells or primary metabolites, which are predominantly associated with microorganisms like yeast or bacteria. It is noteworthy that this approach is cost-effective in terms of both initial investment and ongoing operation.

2. **Airlift Fermentor:** Airlift bioreactors come in two varieties: internal loop type and external loop type. The fermentation process is carried out in a single container with a draft in an internal-loop airlift bioreactor. An external loop in the external loop airlift bioreactor allows samples or liquids to be separated into multiple channels for fermentation. Less energy is used, thus it is economical. The main disadvantage is that there is no shaft to act as a foam breaker.

3. **Packed bed Fermentor:** It is packed full of microbial cells acting as biocatalysts or an immobilized enzyme. Since the enzymes are immobilized, their stability is increased and they can be used repeatedly. It offers superior quality and is simple to use. There is control over the items. External mass transfer resistance arises throughout the reaction as the substrate and product molecules move both inside and outside of the carrier matrix.

4. **Fluidized Bed Fermentor:** A fluidized bed bioreactor represents an immobilized cell reactor, amalgamating characteristics of both stirred tank and continuous flow packed bed reactors. This configuration entails a bed of uniform particles that remain suspended within a flowing liquid medium. It finds application for various particulate materials, including immobilized enzymes, immobilized cells, and microbial flocs. Gravity plays a pivotal role in retaining immobilized-cell particles within the bed. The system encompasses three phases - gas, liquid, and solid - and is deployed in processes like

wastewater treatment and hydrogen production. Notably, achieving fluidization within the fermenter necessitates a higher energy input.

5. **Photo Fermenter:** Photo fermenters are used for the cultivation of algae.It requires temperature between 25-40degree℃. It can save space as it could be placed at indoor or outdoor in an angle or in vertical or horizontal position. The control of PH and temperature is quite difficult. It is somehow susceptible to contamination.

6. **Membrane Fermenter:** It is made up of a biological reactor that uses suspended biomass and membranes for ultra- and microfiltration to remove solids. It is employed in wastewater treatment, organic acid synthesis, solvent manufacturing, and alcoholic fermentation. High-quality effluent is passed through the membranes, doing away with the need for filtration and sedimentation.

   The three most common membrane materials are cellulose acetate, polyamide, and polysulfonte. It is expensive and energy-intensive.

IV. TYPES OF FERMENTATION

1. **Solid state Fermentation (SSF):** The bacteria are cultivated on a damp solid medium with little to no water present in between the particles. The moisture content of the solid medium ranges from 12 to 80%. Foods and agricultural goods like soybeans undergo this kind of fermentation caused by Aspergillus and Rhizopus. Rotating drum, tray, swing solid state, packed bed, air-solid, and stirred vessel are the several types of solid state fermenters.

   Enzymes like pectinase, cellulase, protease, amylase, and phytase are produced using SSF. SSF can also create a variety of secondary metabolites, including gibberellic acid and antibiotics, as well as organic acids like lactic acid and gallic acid. Fatty acids and biocontrol agents are also produced using it. SSF has the advantages of having a high product titre, minimal water use and waste, no foaming problems, low cost, and lower energy requirements. A number of drawbacks of SSF include its limited species list, difficulty in maintaining pH during fermentation, inadequate oxygen delivery, and difficulty in managing the solid substrate's moisture content.

2. **Submerged Fermentation (SmF):** Microorganisms are cultured in an enhanced liquid broth during submerged fermentation. There are numerous industrial applications for this kind of fermentation. The microorganisms are cultivated in a confined container filled with nutrient-rich, highly oxygenated broth. The manufacturing medium, which optimizes based on the microbe and target molecules, is a crucial element. SmF could be implemented in three different ways: continuously, fed batch, and batch mode.

   - **Batch Mode:** It's easy to do; all the necessary ingredients are put into the container, along with an air supply. Sterilization of the fermenter, production medium, and inoculum addition are among the requirements. The process of running a closed fermenter comes to an end when the target molecule reaches its maximum concentration or the nutrient runs out. Batch mode reduces the possibility of contamination and is easy to use. Even an inexperienced operator could manage it.

- **Fed-Batch Mode:** This kind of fermentation occurs when the system isn't operated in a closed fashion. When necessary, more substrates, nutrients, or inducers are given to the system. The bacteria' productive phase is extended by this product addition.High cell density is attained in fed batch mode, which boosts metabolite production.It is possible to regulate the organism's rate of development and oxygen requirement.

- **Continuous Mode :** To keep the organism's volume, biomass rate, production, and substrate concentration constant, it is fed fresh nutrients and has its spent medium and cells removed. Longer periods of productivity are provided, and high cell density is attained. It is possible to study the physiology of culture in this approach.

Microbes are specialized in converting certain substances into others and produce a variety of foodstuffs and beverages.

- **Lactic acid Fermentation:** Bacterial and yeast strains have the ability to convert starches or sugars into lactic acid without the need for heat during the preparation process. In anaerobic chemical reactions, pyruvic acid utilizes nicotinamide adenine dinucleotide + hydrogen (NADH) to generate lactic acid and NAD+. It is worth noting that lactic acid fermentation also occurs in human muscle cells. When engaged in strenuous physical activity, muscles can deplete adenosine triphosphate (ATP) at a faster rate than oxygen is supplied to the muscle cells, leading to the accumulation of lactic acid and subsequent muscle soreness. In such situations, glycolysis, which breaks down a glucose molecule into two pyruvate molecules, operates without the need for oxygen to produce ATP. Lactic acid bacteria play a crucial role in the production and preservation of cost-effective and nutritious foods. This method is commonly employed in the manufacture of sauerkraut, pickles, kimchi, yogurt, and sourdough bread.

- **Acetic acid Fermentation:** Grain and fruit starches and sugars ferment to produce tart vinegar and sauces. Kombucha, wine vinegar, and apple cider vinegar are a few examples.

- **Alcohol Fermentation:** When yeast (S. cerevisiae), some bacteria, or other microorganisms are present, carbohydrates like glucose, sucrose, and fructose are fermented into ethyl alcohol and carbon dioxide. This process is known as ethanol fermentation or alcoholic fermentation. Wine and beer are products of alcohol fermentation.

V. DIFFERENT STAGES OF FERMENTATION

1. **Primary Fermentation:** This is a concise stage during which microorganisms exhibit rapid activity on unprocessed ingredients like fruits, vegetables, or dairy products. The microorganisms found in the surrounding liquid, such as brine for fermenting vegetables, serve as a protective barrier against the proliferation of spoilage-causing bacteria within the food. Within this context, yeasts and various other microbes facilitate the transformation of carbohydrates, specifically sugars, into alternative compounds like alcohols and acids.

2. **Secondary Fermentation:** This constitutes the lengthier phase of fermentation, extending over several days or even weeks. As the alcohol content progressively increases, the microbes and yeast cells eventually perish. In the production of alcoholic beverages like wine and beer, secondary fermentation is employed by winemakers and brewers. The pH levels play a crucial role in influencing the chemical reactions occurring between the microorganisms and their surroundings. Once the alcohol level reaches a range of 12–15%, it proves lethal to the yeast and halts any further fermentation. To boost the alcohol content to a higher percentage, the removal of water and alcohol condensation necessitates the process of distillation.

VI. APPLICATIONS OF FERMENTATION

1. **Production of Cells or Biomass:** Large numbers of cells are produced during the fermentation process, which can be utilized to extract metabolites. An inoculum of microorganisms grows at its maximal rate when cultivated in a production medium that has been appropriately supplemented. The target product can be extracted by down streaming the biomass that has been collected.

2. **Production of Metabolites:** Microorganisms can produce both primary and derived metabolites through the use of fermentation technology. Primary metabolites are created during the microorganism's growth phase. ex citric acid, lysine, threonine, tryptophan, and ethanol.

3. During the stationary phase of their life cycle, bacteria create secondary metabolites. Antibiotics such as penicillin and bacteriocins are examples of secondary metabolites.

4. **Modification of Molecules:** In fermentation technology, cultivation-based or molecular methods can be used to modify metabolic pathways.

5. **Production of Recombinant Product:** Pharmaceutical businesses use fermentation-produced recombinant proteins, vaccines, and hormones extensively.

6. **Absorption:** Food that has undergone fermentation may contain more vitamins and minerals and be easier to absorb. Fermentation improves folic acid, riboflavin, niacin, thiamine, and biotin and boosts vitamins B and C. These vitamins and minerals are more easily absorbed by the body thanks to the lactic acid, enzymes, and probiotics found in fermented foods.

VII. CONCLUSION

Fermentation employs microorganisms and enzymes for the production of compounds utilized in various industries, including pharmaceuticals, chemicals, energy, materials, and food. Initially, fermentation was an age-old technique primarily used in brewing beer. In recent years, the synergy of fermentation technology with biotechnology has been harnessed to create value-added products such as enzymes, hormones, antibiotics, and other metabolites. While the science behind fermentation is intricate, the process itself results from relatively simple and straightforward chemical reactions.

Fermented foods are abundant in probiotics, which play a crucial role in maintaining a healthy gut. The fermentation process generates an acidic environment in the gut that is detrimental to harmful pathogens. Furthermore, fermentation can enhance the mineral and vitamin content of foods. It boosts the levels of biotin, folic acid, thiamine, riboflavin, and niacin, while also increasing the concentrations of vitamins B and C in various food items. The lactic acid, probiotics, and enzymes found in fermented foods facilitate the body's more efficient absorption of these essential minerals and vitamins.

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