Assessing the Efficiency and Challenges of Biological Wastewater Treatment Techniques in Confectionery Industry.

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Abstract

The Increasing global water scarcity and environmental challenges in the food industry are some of the reasons for initiating the development and implementation of sustainable wastewater treatment methods. In this respect, the biological methods for treating wastewater in the confectionery industry are critically examined in relation to aerobic and anaerobic processes. Wastewater coming from confectionery includes a high quantity of organics, generally represented by sugars and lipids, and dyes, accounting for its high values of Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD). In the present paper, an evaluation on the effectiveness of activated sludge in aerobic conditions and of the Up-flow Anaerobic Sludge Blanket (UASB) reactor in anaerobic conditions was performed, showing the advantages and limitations of such treatment processes. The results show that while both techniques are quite efficient in BOD and COD reduction, high operational costs and sensitivity to environmental conditions present continuous challenges. The findings underline the importance of optimizing biological treatment processes to increase the long-term viability and economic sustainability of wastewater management within the confectionery industry. The results highlight the significance of improving biological treatment methods in order to boost wastewater management's long-term sustainability and financial feasibility in the confectionery sector.

Keywords: Activated sludge, Anaerobic digestion, Biological methods, Confectionery industry, Wastewater treatment.

Introduction

Food chains are complex systems that require extensive resources and a variety of skills and factors of production, including technology, labor, logistics, financial, and natural capital [1]. According to Toussaint et al. [2], the growing pressures on the social, economic, and environmental aspects of food production and consumption demand involvement from a wide range of stakeholders to address the increasing awareness and needs of populations and to meet global food demands. In this scenario, the sustainable management of natural water resources is essential for the food processing sector. The journey of food from farms to consumers involves significant water usage, with estimates suggesting that about 70% of the total water required for many staple food crops is used at the farm level [3]. With a projected global population of 10 billion by 2050, the International Union for the Conservation of Nature (IUCN) foresees a 55–60% increase in water demand [4].

The confectionery industry, which has a global reach and significant presence, produces sweets like chocolate and gum, involving considerable amounts of sugar, sugar substitutes, cocoa, fats, emulsifiers, and flavors in its production processes [5-7]. The ecological footprint of water use in high-quality water production includes considerable energy for collection, transportation, treatment, and wastewater management. This involves building water treatment facilities, installing pipelines, housing equipment, using chemical cleaners, and employing labor. Furthermore, water treatment produces sludge, which can be a pollutant if not managed correctly [8,9]. Although water is relatively inexpensive in many areas, the overall costs associated with water extraction, treatment, distribution, and its return to nature are expected to rise significantly. Natural water sources, such as groundwater, rivers, and lakes, are increasingly affected by contamination from chemicals and microorganisms, highlighting the need for careful water management [10].

Protecting water from industrial pollution is crucial for sustainable development. To achieve this, more efficient industrial wastewater purification and the adoption of eco-friendly technologies are necessary [11,12]. Monitoring industrial facilities that discharge wastewater into municipal

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***Received:** 11-Sep-2024, Manuscript No. AABB-24-147801; **Editor assigned:** 12-Sept-2024, Pre QC No. AABB-24-147801 (PQ); **Reviewed:** 21-Sept-2024, QC No. AABB-24-147801; **Revised:** 26-Sept-2024, Manuscript No. AABB-24-147801 (R); **Published:** 30-Sept-2024, DOI:10.35841/aabb-7.5.221*

***Citation:** Zarif N. Assessing the Efficiency and Challenges of Biological Wastewater Treatment Techniques in Confectionery Industry. J Biochem Biotech 2024; 7(5):221*

systems is an effective method of pollution control, though it can be very costly, particularly in highly industrialized regions [13].

Climate change and environmental degradation are expected to affect standard practices in the food industry, which may be currently considered routine, due to increasing water scarcity. A significant amount of water is used for cleaning and hygiene in food manufacturing and personal routines, such as handwashing, showering, shoe disinfection, laundering, and sanitation. Additionally, substantial water use is required for cleaning and sanitizing equipment and installations at the end of production batches. Therefore, it is crucial to adopt alternative food processing methods that focus on water recycling and reuse [14]. Implementing water-saving measures can provide both environmental and economic benefits to businesses, leading to long-term cost savings [15].

This review emphasizes biological methods for treating wastewater produced by the confectionery industry.

Characteristics and variations of organic load in confectionary wastewater

In the confectionery industry, the primary source of wastewater is the cleaning process of production equipment, with the volume of sewage generated varying according to the frequency of cleaning. Consequently, the composition and quantity of wastewater exhibit both daily and seasonal fluctuations, which impact its disposal process. Confectionery facilities typically discharge approximately 300-500 cubic meters of technological wastewater per month [16]. This wastewater is biodegradable and predominantly consists of organic compounds and suspended solids, leading to elevated levels of chemical oxygen demand (COD) and biological oxygen demand (BOD) [17]. The organic materials in the wastewater include sugars, fats, and colorants [18, 19, 7, 15, 12]. Additionally, the wastewater often contains residues from cleaning and disinfecting agents, which can alter the pH and increase the concentration of nitrogen and phosphorus compounds [17].

Evolution and methods of industrial Wastewater treatment

Wastewater treatment is a relatively recent development. Mechanical and biological processes for treating municipal wastewater began to take shape by the late 19th century [20]. Modern industrial wastewater treatment technology incorporates a combination of mechanical, physicochemical, and biological methods (**Figure 1**) [21].

Biological methods

The use of activated sludge

Activated sludge treatment under aerobic conditions is a widely employed method for wastewater treatment [22, 23], although its costs can often be prohibitively high for industrial applications [24]. This method involves a biological system where both physical and biochemical processes occur. Essentially, it is a suspension of flocculent clusters of heterotrophic bacteria. The physical processes occur on the surface of these flocks, involving the adsorption of organic compounds which are then broken down into smaller fragments. These fragments are subsequently absorbed by microbial cells and further transformed. Bacteria in the activated sludge generate enzymes that facilitate a series of biochemical reactions, leading to the breakdown of inorganic and organic compounds in the wastewater [23]. Activated sludge treatment has been applied in various confectionery facilities. For instance, El Diwani et al. (2000) [25] developed an integrated pilot plant for treating wastewater from gum and candy production, which included an equalizer, chemical mixer, aerator, clarifier, disinfectant tank, and sand filter. This system reduced the BOD from 3200 mg/L to 70 mg/L and the COD from 5000 mg/L to 100 mg/L. Laboratory experiments using periodic operation reactors (SBR) also demonstrated

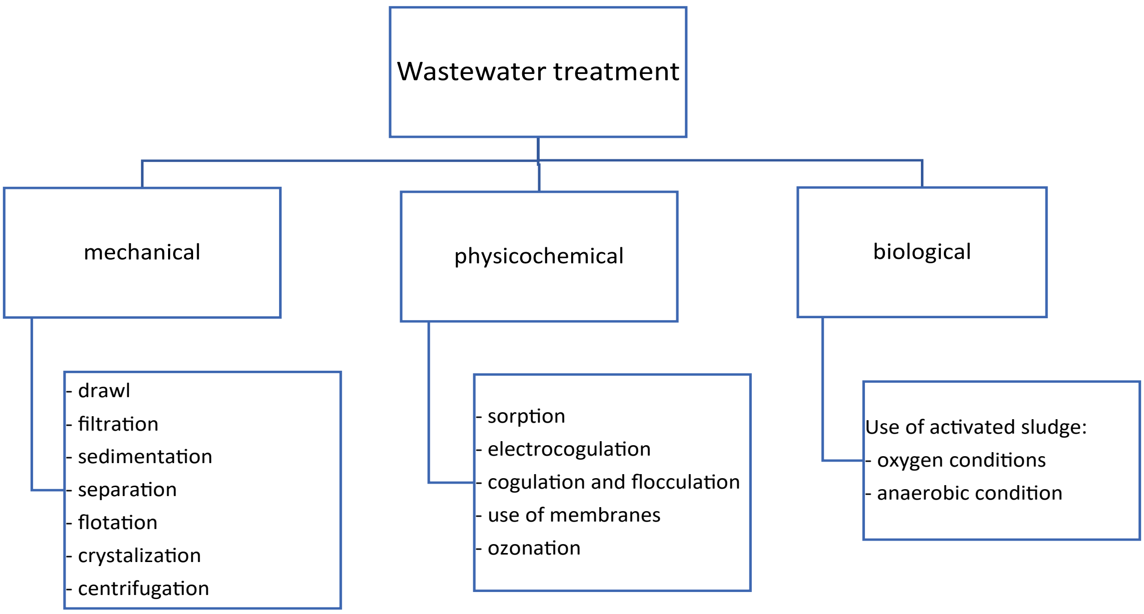

Figure 1: *Wastewater treatment methods.*

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Table 1. *The advantages and disadvantages of the activated sludge under aerobic conditions in the wastewater treatment technology [24].*

Advantages	- lack of odours - high reduction of BOD and COD
Disadvantages	- complicated technique - high operating costs - formation of a large amount of sludge - sudden increase in volume or change in the composition of sewage may have a negative effect on the operation of the process

Table 2. *The advantages and disadvantages of the biological treatment under anaerobic conditions in the wastewater treatment technology [24].*

Advantages	- possibility of energy recovery - high reduction of BOD and COD - low sludge production compared to oxygen methods
Disadvantages	- high operating and maintenance costs - considerable sensitivity of methanogenic bacteria to changes in environmental conditions - need for expansion tanks

over 95% efficiency in removing COD and BOD, with the treated wastewater significantly meeting the permissible discharge standards [26]. However, the main drawbacks of these technologies include high costs, complex procedures, and the potential for loss of compacted bacteria in the activated sludge [24] (**Table 1**).

Treatment under anaerobic conditions

Anaerobic treatment relies on a microbiological process such as methane fermentation, where specific bacterial strains convert the organic waste in sewage into biogas, including methane and CO2. The bacteria involved in this process are present in anaerobic sludge, which can be either flocculent or granular. Various wastewater treatment methods utilize anaerobic technologies. Anaerobic digestion is employed not only for a range of waste types but also for biosolids [27, 24]. In recent years, the Up-flow Anaerobic Sludge Blanket (UASB) reactor has gained popularity and is extensively used for treating different types of wastewaters [28]. This reactor's benefits include high removal efficiency even at low temperatures, low energy consumption, and minimal space requirements. It is particularly effective for treating organic wastewater due to its high biomass concentration and diverse microbial community [29].

Tanksali (2013) [30] utilized a UASB reactor with nongranular anaerobic activated sludge to treat wastewater from a sugarcane factory under laboratory conditions at temperatures between 26-39°C. This setup achieved a high COD removal efficiency of 80% to 96%, with a maximum biogas production of 13.72 L/d and a methane concentration of 71% in the biogas. Atashi et al. (2010) [31] also used the UASB reactor to treat wastewater from a sugar factory, obtaining a COD reduction of 90% at a pH of 7 and temperatures of 35-38°C.

Park et al. (2001) [24] performed pilot-scale treatment of sewage from squid processing, achieving a BOD reduction of approximately 80%. The estimated capital costs for this technology were USD 490,000, with annual operating costs of USD 45,000 (**Table 2**).

Conclusion

This review reviewed the efficiency and challenges of biological methods of wastewater treatment in the confectionery industries, including both the aerobic and anaerobic methods. It included aerobic conditions using activated sludge and anaerobic conditions with the UASB reactor for effective removal of high levels of BOD and COD, representative of wastewater generated in confectionery industries. The potential of both methods was considerable in handling these normally high organic loads typical of this industry.

While effective in realizing high BOD and COD removal efficiencies, the activated sludge system poses a number of problems in terms of high operation costs, complicated technology, and high production of sludge. Similarly, the UASB reactor also possesses advantages including reduced consumption of energy, with high removal efficiencies even at lower temperatures. This too is not without its disadvantages: high maintenance cost and sensitivity to environmental conditions.

The results draw an immediate call for further research and development to ensure that these biological treatment processes are optimized. Moreover, considering the growing shortage of water globally and increasing wastewater volumes produced by the confectionery industry, there is a need for further improvement in the economic viability and robustness of the operating technology. The integration of aerobic and anaerobic processes to get the best out of their synergies is likely to be a subject of interest in the future, as will hybrid systems that could iron out the particular drawbacks of either process in its entirety.

Therefore, the pursuit of deeper innovative solutions in order to reduce difficulties in operations-such as improved stability of microbial communities and reduced excess sludge formation-will also is important for further improvement in sustainability at wastewater management. Water conservation and eco-friendly technologies will go a long way in benefiting the confectionery industry not only economically but also in extending new horizons toward sustainable practices.

While current biological treatment methods might look promising, their successful application to confectionery industries depends on how operational hurdles are overcome and processes optimized for both efficiency and cost-effectiveness. Long-term sustainability and ecological wastewater management will absolutely be necessary in view of growing environmental pressures.

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