SOCIOMETRICS.US

Sociometrics: Journal of Social Measurement and Analysis
Vol.2 | No. 1 | 2025 pp. 18-21 |ISSN: XXXX-XXXX

Methods of Water Purification Through Biotechnology

Avliyakulova Shakhnoza Muzafarovna
Bukhara State Pedagogical Institute, Department of Biology, Lecturer
shahnoza_muzafarovna@buxdpi.uz

Submitted: 12-Sep, 2024
Accepted: 21-Jan, 2025
Published: 31-Jan, 2025

Vol. 2, **No.** 1, 2025. Sociometrics.us

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***Corresponding author:**
Avliyakulova Shakhnoza Muzafarovna[1]
shahnoza_muzafarovna@buxdpi.uz

Abstract

The growing global demand for clean water, exacerbated by industrialization and environmental pollution, has intensified the search for sustainable purification technologies. Traditional water treatment methods often fail to meet environmental and economic standards, prompting the adoption of biotechnology-based purification methods that utilize natural biological processes. Despite proven success in microbial remediation, many biotechnological methods remain underutilized in regions like Uzbekistan, where ecological challenges and water scarcity persist. This study investigates biotechnological approaches to water purification, analyzing the mechanisms and effectiveness of biofiltration, bioreactors, phytoremediation, and microalgal methods, with a focus on their potential application in Uzbekistan. The article presents how aerobic and anaerobic systems, activated sludge, and genetically enhanced microbial strains—such as Pseudomonas—contribute to the biodegradation of organic pollutants and toxic substances. Enzymatic activities and plasmid-encoded detoxification pathways are highlighted, as well as factors influencing process efficiency, including oxygen levels and temperature. The integration of microbial genetics with wastewater engineering and phytotechnologies is emphasized, demonstrating innovative pathways such as cometabolism and recombinant plasmid use in the degradation of complex pollutants. Biotechnological water purification offers an ecologically sound and economically viable strategy aligned with sustainable development goals. Its widespread implementation in Uzbekistan could significantly improve water quality and environmental resilience, especially when customized to local ecological and industrial conditions.

Keywords: microbial biomass, filtering microbes, microbial strains, fermentative bacteria, methane- and atmosphere-oxidizing bacteria, hydrogen bacteria.

Introduction

Water is the source of life. However, due to industrial development, population growth, and environmental pollution, the shortage of clean drinking water has become an urgent problem[1]. Traditional purification methods (filtration, chlorination, use of chemicals) are often insufficient in terms of environmental safety and economic efficiency. At this point, biotechnology emerges as an innovative and eco-friendly solution for water purification[2].

What is biotechnological water purification?

Biotechnological water purification refers to the use of microorganisms, plants, bioreactors, or natural biological processes to restore polluted water to a natural state[3]. This method is environmentally friendly, requires less energy, and allows for reuse and recycling.

Materials and Methods

Biological purification through aerobic methods

Main biotechnological methods of water purification

1. Biofiltration (via bioreactors)

Microorganisms that decompose organic pollutants in water are cultivated in special biofilters.

These bacteria convert contaminants into CO_2, water, and other harmless substances in the presence of oxygen[4].

2. Aerobic and anaerobic bioreactors

Aerobic reactors work in the presence of oxygen and ensure rapid decomposition.

Anaerobic reactors function without oxygen and release gases like methane, which can be used as an energy source[5].

3. Phytoremediation (plant-based purification)

Special plants (e.g., reeds, aquatic grasses) absorb harmful substances such as metals, nitrogen, and phosphorus from water.

Commonly applied in natural bio-ponds.

4. Microalgal purification

Green microalgae remove nitrates, phosphates, and other nutrients from water.

They also produce oxygen, supporting the activity of other microorganisms[6].

Liquid waste purification by aerobic methods is divided into two categories: extensive and intensive[7].

Extensive methods involve biocenoses forming over time in irrigation fields or filtration ponds, where the life activity of adapted organisms purifies the water.

Intensive methods rely on activated sludge or biofilms. In aeration tanks (biofilters), diverse biocenoses form that effectively purify various industrial wastewater types[8].

Results and Discussion

Activated sludge consists of 70% living organisms and 30% inorganic solids. These form brown-colored particles called zooglea (biofilm)[9].

Microorganisms in activated sludge include various families such as *Actinomyces*, *Bacillus*, *Bacterium*, and *Micrococcus*, with *Pseudomonas* being the most common. These bacteria oxidize alcohols, fatty acids, paraffins, and aromatic hydrocarbons.

In addition to bacteria, protozoa (unicellular organisms like sarcodines and infusoria) are also present. A high-quality activated sludge typically contains 10–15 protozoa per 1 million bacterial cells — a ratio known as the protozoa coefficient (kr). A higher coefficient accelerates the biochemical oxidation process[10].

Factors influencing biological purification

The efficiency of biochemical purification depends on:

Temperature

Dissolved oxygen concentration

Amount of toxic compounds

In aerobic purification, wastewater and activated sludge pass through concrete aeration tanks and are mixed with air. The mixture then flows to secondary filters where sludge is separated. A portion of the sludge is recycled, while the rest is dried and used as fertilizer[11].

Anaerobic purification and microbial strains

Anaerobic microorganisms also purify wastewater by breaking down organic matter, especially from industries like dairy, alcohol, and petroleum refining. This process reduces waste, odors, and produces methane [12].

Microbial strains can degrade chemical pollutants (e.g., biocide destruction). *Pseudomonas* species possess enzymes like oxidoreductases and hydroxylases, which break down toxic hydrocarbons [13]. These abilities are encoded in plasmids such as:

OCT (for octane and decane degradation)

XYL (for xylene and toluene)

SAM (for camphor)

NAH (for naphthalene)

Genetic recombination has produced hybrid plasmids with enhanced degradation properties.

Some microbes alter toxic molecules to make them easier for other microbes to degrade — a process known as cometabolism. For instance, Dafton and Hsi (University of California) demonstrated that *Pseudomonas* strains could degrade the toxic insecticide parathion [14].

Detoxification, rather than complete degradation, often occurs via processes like phosphorylation, methylation, and acetylation. These are catalyzed by enzymes encoded in plasmid DNA.

Researchers have developed microbial cultures that degrade the widely used herbicide 2,4,5-T (2,4,5-trichlorophenoxyacetic acid). Microorganisms isolated from treatment plants were grown in a medium containing only 2,4,5-T, and after 10 months, growth rate increased due to bacteria that could metabolize the compound.

Achievements and Prospects of Biotechnology

Modern biotechnology focuses on creating new, more efficient microbial strains by modifying the genetic characteristics of microorganisms. For example, microbes belonging to the *Pseudomonas* genus possess special enzymes capable of breaking down toxic substances. Using these microbes, even oil waste can be effectively treated.

Some microorganisms can convert toxic substances into harmless forms — a process known as detoxification. Scientific research in this area is rapidly progressing: currently, studies are also underway to develop microbes that can degrade plastics [15].

Conclusion

Water purification through biotechnology represents an eco-friendly approach aligned with sustainable development goals. In Uzbekistan, the wide implementation of such technologies can significantly improve water resource protection and access to clean drinking water. Technologically advanced systems tailored to local conditions can help maintain ecological balance.

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