Sustainable Treatment of Wastewater Using Microorganisms

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Abstract

The treatment of wastewater is an important aspect in preserving water, an increasingly pressing issue as available water for consumption lessens. Wastewater is considered unusable due to high levels of contaminants and toxins, making it unfit for both human consumption and its return into the natural environment. Wastewater treatment plants are therefore implemented to allow for wastewater to be recycled and used again in the future. However, wastewater treatment methods vary in sustainability, with several conventional treatment methods proving to potentially hold harm to the environment by producing harmful byproducts during the process. Sustainable treatment of wastewater is crucial to ensuring the effectiveness of treatment and the safety of its future usage. The utilization of microorganisms during the treatment process poses as a promising solution to this. This paper will examine the viability of using microorganisms during the treatment process as a potential primary form of wastewater treatment. The paper will outline the wastewater treatment process using microorganisms, detail what function microorganisms serve to be sustainable, provide real-world implementation examples, and analyze the advantages and limitations and provide solutions to overcome the limitations with this treatment process.

Introduction

In the current era, water scarcity is becoming an increasingly severe issue for everyone. Exponential population growth is causing a greater demand for more water, which water supplies at the moment cannot meet. Existing supplies of water must be well conserved to alleviate this severe water shortage. One aspect of water retainment is wastewater treatment: by recycling and utilizing previously used water, strain for fresh water is reduced. Wastewater treatment is therefore incredibly important in the conservation of the environment and the health of humans.

In its initial state, wastewater is considered unusable for consumption due to the high concentrations of contamination, which also make returning said water to sources like rivers bad for the environment. Bodies of water affected by high levels of contamination often lead to growth of harmful algae which impacts the quality of water and increases aquatic death counts. Furthermore, increased contamination of heavy metals and other toxic chemicals create danger for aquatic consumption. In wastewater treatment plants, these contaminants are effectively removed from waters so that they can be reintroduced to the environment with no dangers.

Multiple forms of treatment exist for wastewater, and while forms vary depending on function and cost-efficiency, the sustainable treatment, the one concerning environmental protection - is also becoming an increasing priority. The variety of forms that exist for wastewater treatment have several environmental consequences related to its usage, such as the creation of harmful byproducts, the usage of synthetic processes, high energy consumption, and more. Sustainable forms of wastewater treatment that do not suffer from these issues must be researched to prevent more harmful wastewater byproducts, and the most promising form is utilizing microorganisms in the treatment process. The microbial treatment of wastewater focuses on the usage of microorganisms, particularly aerobic and anaerobic bacteria, as tools to decontaminate and treat polluted wastewater.

Overview of the wastewater treatment process

To ensure high quality treatment, wastewater undergoes an elaborate process that is divided into multiple major stages. We will outline the stages here. **The first step** of sustainable water treatment is collection. Water from rivers, reservoirs, lakes, etc. are collected to be treated in this stage. The collected water is then transported to the treatment plant through networks of pipes and pumps. At this point, the treatment starts. **Screening:** The incoming water passes through screening equipment where large fragments of trash such as rags, wood, plastics, and grease are filtered out and removed. Fine materials like grit, sand, and gravel are also removed in this stage. The wastewater continues through the treatment plant, while the filtered waste fragments and grit are gathered and disposed of at a landfill. **Primary Settling:** In the next stage, chemicals called coagulants are added to force tiny particles to cluster together and create a 'floc'. These coagulants are mixed together at varying speeds over a long period of time to create as many flocs as possible. Large circular tanks called clarifiers then take out these materials, with the settled material, called primary sludge, remaining. This primary sludge is taken from the bottom and the remaining wastewater exits from the top of the tank. **Activated Sludge:** In this step, the wastewater receives most of its treatment. Through biological degradation, the pollutants are consumed by microorganisms and transformed into cell tissue, water, and nitrogen. The biological activity occurring in this step is very similar to what occurs at the bottom of lakes and rivers, but in these areas the degradation takes years to accomplish. **Secondary Settling:** Large circular tanks called secondary clarifiers allow the treated wastewater to separate from the biology from the aeration tanks at this step, yielding an effluent, which is now over 90% treated. The biology (activated sludge) is continuously pumped from the bottom of the clarifiers and returned to the aeration tanks in step four. **Filtration:** The clarified effluent is polished in this step by filtering through 10-micron polyester media. The material captured on the surface of the disc filters is periodically backwashed and returned to the head of the plant for treatment. **Disinfection:** To assure the treated wastewater is virtually free of bacteria, ultraviolet disinfection is used after the filtration step. The ultraviolet treatment process kills remaining bacteria to levels within our discharge permit. **Oxygen Uptake:** The treated water, now in a very stabilized high-quality state, is aerated if necessary to bring the dissolved oxygen up to permit level. After this step, the treated water passes through the effluent outfall where it joins the river. The water discharged to the river must meet stringent requirements set by the DNR.

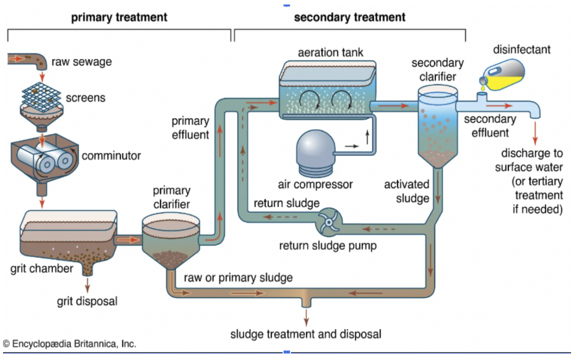


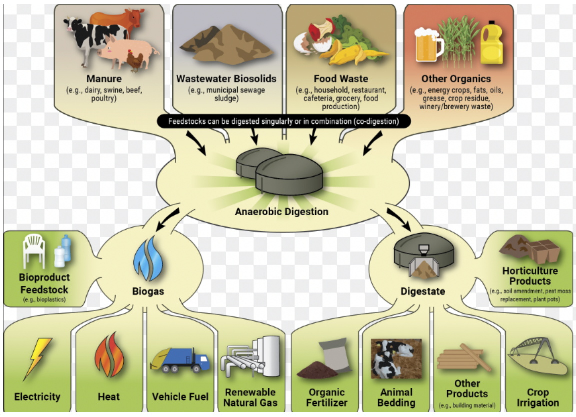
Figure 1: graphical representation of the wastewater treatment process

Anaerobic and Aerobic Microbial Treatment Phases

In this process, both aerobic and anaerobic bacteria are utilized. Aerobic bacteria rely on oxygen to survive, and are primarily used in the initial stage of wastewater treatment. In the initial stages, large amounts of organic matter are present within the water. Aerobic bacteria decompose these complex substances into simple compounds like carbon dioxide. Anaerobic bacteria can survive without oxygen, and use anaerobic digestion to break other complex substances into methane gas, which can be sustainably used for renewable energy. Through these two processes, microorganisms are used to sustainably and systematically treat wastewater. Microbial biotechnology offers innovative scientific applications of great ecological and economic interest. It effectively exploits natural degradation processes to treat pollution. This method is significantly less expensive than conventional physical-chemical or mechanical techniques. The use of bacteria is different from usual treatment methods in that it uses simple, natural processes. Their performance results in pollution treatment without the creation of new contaminations. Most of the time, their installation requires the use of a dedicated bioreactor, as well as the nutrients necessary for their multiplication in large numbers. Dosing is easy and requires little operating time. The purpose of this study is to examine the effects of microbial treatment of wastewater. Examine social benefits and cost, efficiency, and its usage over traditional forms of treatments.

Aerobic: Aerobic bacteria are mostly used in new treatment plants in what is known as an aerated environment. This bacterium uses the free oxygen within the water to degrade the pollutants in the wastewater and then converts it into energy that it can use to grow and reproduce. For this type of bacteria to be used correctly, it must have oxygen added mechanically. This will ensure the bacteria are able to do their job correctly and continue to grow and reproduce on its food source.

Anaerobic: Anaerobic bacteria are used in wastewater treatment on a normal basis. The main role of these bacteria in sewage treatment is to reduce the volume of sludge and produce methane gas from it. The great thing about this type of bacteria and why it's used more frequently than aerobic bacteria is that the methane gas, if cleaned and handled properly, can be used as an alternative energy source. This is a huge benefit considering the already high wastewater treatment energy consumption levels. Unlike aerobic bacteria, this type of bacteria is able to get more than enough oxygen from its food source and will not require adding oxygen to help do its job. Phosphorus removal from wastewater is another benefit of anaerobic microbes used in sewage treatment.



Application of microbial wastewater treatment

The usage of microorganisms as a sustainable alternative to conventional methods of wastewater treatment has yielded more successful results across multiple different test cases.

Iran Case Study: One paper found the effects of Iranian wastewater plants and their effectiveness in removing contaminants and other harmful agents from wastewater. A review was conducted gathering information published from five different Iranian environmental health journals over 11 years, and looked to see how effective wastewater treatments were at removing microbial agents. The methodology used to determine the effectiveness of treatment was by identifying the number of samples, the type of purification, the type of microbial agents and the rate of removal of microbial agents across the different articles issued by the Iranian environmental journal. Results found that Total Coliforms and Fecal Coliforms, two of the most prevalent bacteria within untreated wastewater, were adequately removed across all treatment plants. The overall removal rates of harmful wastewater viruses from the activated sludge, oxidation pools, activated carbon filtration, and coagulation processes was 50-90%, showing extensive success in the microbial treatment methods implemented across Iranian wastewater treatment plants.

Microbial treatment advantages

Microorganisms as the primary form of wastewater treatment holds several advantages over other traditional forms.

Firstly, microbial treatment is very effective in cleaning wastewater of harmful substances. Aerobic bacteria used during aeration prevents the accumulation of fats, oils, and greases in waters, while anaerobic bacteria in the secondary treatment phase reduces total suspended solids. Furthermore, both aerobic and anaerobic bacteria play a pivotal role in reducing biochemical oxygen demand. High levels of this demand lead to oxygen deprivation within aquatic systems that the wastewater is eventually dumped to, which affects the biodiversity and health of reintroduced bodies of water. These microbial treatments are not only more effective but also more cost-efficient, with anaerobic treatments producing less sludge that aids in waste management across treatment stages.

Microorganisms also serve as a sustainable and environmentally friendly alternative to other methods, because this treatment does not involve the addition of harmful chemicals.

More environmentally friendly compared to conventional chemical treatment methods as it does not involve addition of harmful chemicals nor any harmful byproducts. On the contrary, the anaerobic treatment actually generates biogas in the form of methane and other renewable gases that can be used as sustainable energy sources.

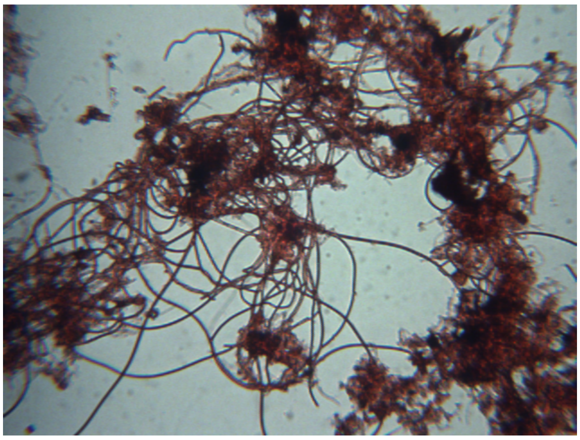
Overall, microorganisms are both more effective and sustainable than conventional forms; however, there are still many limitations to consider before implementing this treatment to all plants.

Limitations of microbial treatment

However, there are many limitations that prevent the microbial treatment of wastewater. These limitations prevent the complete adoption of microbial treatment as the primary form of wastewater treatment, and these limitations must be discussed on how to more sustainably treat wastewater moving forward.

The biggest weakness with microbial treatment is its sensitivity to the conditions in which it is operated. Temperature is one such condition: microorganisms have no method to regulate their internal temperature, so they adapt to the surrounding environment's temperature to properly survive. The optimal temperature range for microorganisms is different for all, but generally, the most common mesophilic bacteria seek a temperature of around 20-45 °C: any lower than this causes decreased metabolic rates and enzyme activity, while higher temperatures denature proteins within the microorganism, causing cell death, making temperature control crucial (biology textbook). Regulating acidity levels is another important condition. Acidity is measured by pH, the negative logarithm of the concentration of hydrogen ions in a solution. Neutral conditions are important for proper wastewater treatment: drastically increasing or decreasing acidity in the solution will cause major problems to the function of the microorganisms, causing issues like the denaturing of proteins that destroy its ability to function.

Changes in treatment conditions lead to another problem: the growth of filamentous bacteria. Filamentous bacteria are microorganisms whose cells failed to detach from one another during cell division, which leads to large strands of cells that resemble filaments. Filamentous bacteria in wastewater treatment plants causes issues with sludge settling during the treatment process, leading to excess bulking of sludge and blocks in aeration tanks and clarifiers. Overall, filamentous bacteria slow down the treatment process by creating excess material.



Filamentous bacteria

Overcoming limitations

The limitations presented regarding the controlling of variables like temperature and pH represent an issue with cost and careful management, which can be achieved through the implementation of rising Artificial Intelligence (AI) technologies. AI is beneficial in the treatment plants as it allows facilities to achieve higher levels of efficiency while using machines.

AI can be utilized during multiple steps of the wastewater treatment process to mitigate the limitations of the sensitivity issues with the treatment environment. Firstly, due to AI's lack of fatigue, it can constantly monitor and adjust the environmental conditions such as temperature, oxygen levels, and pH using different sensors to create an ideal environment for activating microorganisms. Any minor disturbance can be immediately fixed. Furthermore, AI can provide the appropriate nutrients for stimulating microbial activity. Aerobic bacteria require a constant flow of oxygen to function during the treatment process: absence of these crucial nutrients will hinder and delay the efficiency. AI can continuously monitor the process of microorganism activation and provide feedback as needed to achieve efficient environmental care.

In the case of the excessive production of filamentous bacteria, more elaborate controlling processes must be taken. The chemical method of suppression is a common form of suppression: chemicals like Cl_2, H_2O_2, and metals all have the capacity to control the growth of filamentous bacteria; however, they are often cited to have potential danger in ruining the microbial ecology within the wastewater treatment plants. More specific strategies like synthetic polymer-based control - the usage of anionic and cationic polymers to control bulking - or quorum sensing - the detection of chemical signaling molecules known as auto-inducers that change bacteria genetics - exist, but further research is required to implement them at the wide scale.

Conclusion

This study examined the role microorganisms played in the treatment of wastewater by examining how it fits in with the overall biological process of treating wastewater, finding its applications in countries through the examinations of case studies, weighing advantages and limitations of microorganism use, and reviewing recent trends of research in these fields. This study found that microorganisms like aerobic and anaerobic bacteria are very well suitable for the treatment of wastewater for both its efficiency and its sustainability applications. The contamination of wastewater is a serious problem that underlies a bigger issue of water scarcity; an issue that must be solved using sustainable means like the microbial treatment of wastewater. Through aerobic and anaerobic processes, microbes facilitate the removal of organic matter, nutrients, pathogens, and emerging contaminants, ultimately producing treated effluent that meets regulatory standards for safe discharge or reuse. The application of microbial treatment technologies not only protects aquatic ecosystems but also contributes to the sustainable management of water resources, aligning with the principles of a circular economy. But while aerobic and anaerobic processes are both sustainable and efficient, there are still undeniably many limitations that prevent it from its wide scale implementation across all wastewater treatment plants. These include the inefficient removal of pathogens, variability in efficiency, higher management costs, and sensitivity to environmental conditions. These limitations make implementation across all facilities difficult, and in the future, facilities must be upgraded to accommodate for these flaws. Ongoing research efforts are focused on optimizing microbial treatment processes, enhancing their efficiency, and exploring novel approaches, such as the integration of advanced oxidation processes, membrane bioreactors, and the application of bioaugmentation and biostimulation strategies. Additionally, the development of molecular techniques and omics-based approaches has provided valuable insights into the complex microbial communities involved in wastewater treatment, enabling more targeted and effective process optimization. Overall, the field of research for microorganisms to be utilized in wastewater treatment holds a promising outlook for the future of sustainable treatment for wastewater. With more time to upgrade facilities and further research to minimize the limitations of microorganisms, wastewater treatment can become entirely sustainable and efficient, recycling high quality water and being better for the environment.

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