Optimizing Bioaugmentation Strategies for Industrial Wastewater Treatment

Himanshu Ramesh Lamba

Abstract: ***Industrial wastewater stands as a significant contributor to pollution, posing challenges for industries to meet compliance requirements despite advanced technologies. This paper aims to identify and address factors influencing bioaugmentation in industrial wastewater treatment. Bioaugmentation in this context presents various challenges, with factors such as pH, temperature and nutrient availability time playing critical roles in determining its effectiveness. The paper concentrates on exploring the impact of these factors on the biological treatment of wastewater and suggests potential solutions.***

Keywords: Industrial Wastewater, Biological, Bioaugmentation, pH, Temperature, Bacteria

1. Introduction

Water is a fundamental resource for industrial operations; thus, the effective management of water resources becomes critical for industries to ensure the sustainability and longevity of their operations. The significant presence of pollutants in industrial wastewater poses a considerable environmental threat, with the potential to adversely affect water quality and public health. Managing water utilities in industries presents a key challenge, particularly in the disposal of wastewater. The release of industrial effluents into water bodies poses a risk of pollution, resulting in significant environmental and health consequences. In response to this issue, industries are increasingly adopting diverse wastewater treatment technologies, including physical, chemical, and biological treatment methods. As industries grow and a greater number of industries coming up, the volume of generated wastewater is also increasing, leading to increased pollution of water resources. There are huge number of industries that are facing challenges in possessing the necessary infrastructure and technology to effectively treat their wastewater, leading to the release of untreated or inadequately treated wastewater into water bodies. [1]

Biological treatment is employed as one of the methods to treat industrial wastewater, involving the breakdown of complex organic compounds within the wastewater using microorganisms. Biological treatment is typically integrated into the overall treatment process, although it can also function independently as a standalone treatment. The choice often depends on the strength of the wastewater, indicating the degree of pollution that requires treatment.

2. Biological Treatment of Wastewater

In biological wastewater treatment, microbes in either a suspended or attached growth reactor help break down organic material through a process of oxidation. Both reactor types use mixed cultures, containing various microbial species. These systems self - optimize, with the most competitive organisms for specific conditions dominating. Changes in environmental conditions, like temperature shifts, alter the species dominance. Bacteria are the main microorganisms in biological wastewater treatment, while higher organisms like protozoa, rotifers, etc have indirect impacts on the process. When organic material breaks down in wastewater, it produces 2 components: new cells and carbon di - oxide. New cells, which are considered waste, need to be removed from the treated water because they add to the carbon load in the receiving water. On the other hand, carbon dioxide doesn't burden receiving waters. Bacteria working in the biological reactors require oxygen, nitrogen, and phosphorus. Oxygen is crucial for the process, and nitrogen and phosphorus are part of the bacterial cells formed. Although other trace elements are needed, wastewater usually has enough. Municipal wastewater typically contains surplus nitrogen and phosphorus, requiring no additional treatment, while certain industrial wastes may lack sufficient nitrogen or phosphorus, necessitating their addition during treatment. [2]

Suspended growth treatment involves microorganisms suspended in liquid. It can be aerobic, anoxic, or anaerobic. Aerobic processes are common in municipal and industrial treatment, while anaerobic methods handle high - strength industrial wastewaters. The activated sludge process is the most common type of suspended growth biological treatment process for municipal wastewater treatment. [3] In contrast to the suspended growth treatment, microorganisms in attached growth systems attach to carriers such as rocks, plastic, polyethylene, or plant materials, forming a biofilm. Two common attached growth systems used in wastewater treatment are trickling filters and rotating biological contactors (RBCs) [4]

3. Bioaugmentation and its Importance

Bioaugmentation, which involves the introduction of microorganisms, is employed to enhance treatment, specifically targeting the removal of priority pollutants. However, Bioaugmentation has faced skepticism regarding its effectiveness in treatment processes. Reported failures are linked to factors like slow growth rates, less information available on how much to dose, and substrate availability. Overcoming bioaugmentation limitations involves techniques such as shock - dosing the reactor, pre - acclimatization in side - stream reactors, nutrient, and surfactant addition, and ensuring adequate acclimatization periods. [5] Experts widely recommend shock dosing, as it involves introducing a substantial population of beneficial microorganisms into the system all at once, encouraging competitionwith the native biology. The purpose of bio augmenting a system is not to replace the existing native biology in the reactor with specialized microorganisms tailored for specific pollutants. Instead, it aims to establish an environment where the native biology works together with the bioaugmented microorganisms, enhancing the efficiency of the treatment plant. Benefits of bioaugmentation may include improved operating stability, expedited commissioning, resilience to shock loads, and improved performance in cold weather. Bioaugmentation results are not guaranteed, and success is influenced by factors such as strain selection, implementation, and maintenance techniques, and understanding the capabilities of commercially available products. [5]

4. Bioaugmentation Dose Rate Calculations

Commercial microbial products for bioaugmentation typically come with recommended dose rates ranging from 0.5 mg/l to 10 mg/l. The appropriate dosage depends on factors such as microbial consortia, delivery mode, mode of action, intended benefits, etc. The initial or starting dosage, known as the shock dose, is chosen to kickstart the bioaugmentation process. After the biological system stabilizes, the plant can continue with a maintenance dose, usually set at 10 times lower than the initial shock dose.

Two methods can be employed to calculate the dose rate: 1) using the influent flow rate and 2) using the volume of the biological system. The second approach would be more suitable for surface water applications like lakes, ponds, and lagoons.

Method 1: Using the influent flow rate [6]

Let's assume the influent flow rate is 3000 m^3/day

Table 1: Calculating Dose Rate using the wastewater influent flow rate

Method 1: Bioaugmentation Technology Dose Calculation		
		Unit
Influent Flow Rate	3000	m^3/day
Initial Bioaugmentation Dosage Rate	5	mg/l
Bioaugmentation Technology (powder*)	15.00	kg/day

For instance, in a 30 - day bioaugmentation program, the schedule might include an initial shock dose at 5 ppm (15 kg/day), followed by 10 days at 2 ppm (6 kg/day), with the remaining days at a dosage rate of 1 ppm (3 kg/day). This would require a total of 129 kg of bioaugmentation technology, which consists of cultured microorganisms in powder form.

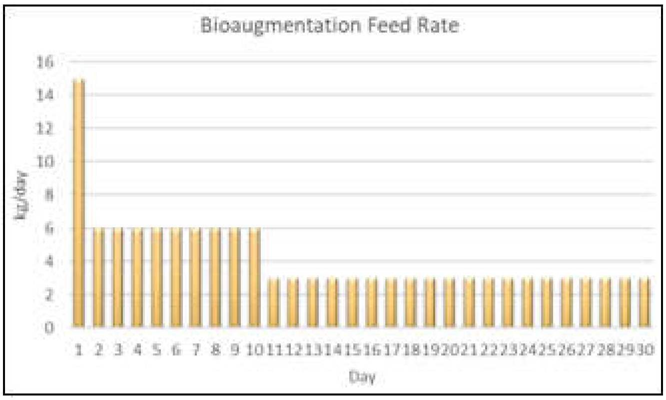

Figure 2: Graph showing Bioaugmentation Feed Rate for Method 1

Method 2: Using volume of biological system

Let's assume the volume of the lagoon is 25, 000 m^3

Table 2: Calculating Dose Rate using the reactor volume

Method 2: Bioaugmentation Technology Dose Calculation		
		Unit
Volume of the Biological System / Reactor	25, 000	m^3/day
Initial Bioaugmentation Dosage Rate	2	mg/l
Bioaugmentation Technology (powder*)	50.00	kg/day

In year - long surface water bioremediation projects, for example, in the case of planning to bioaugment a lake with a volume of 25, 000 m^3, the recommended initial shock dose for week 1 would be 50 kg/week, followed by a regular weekly maintenance dose of 12.5 kg/week for the rest of the year. It's important to note that this recommendation is most suitable for surface water applications infiltrated with sewage water or agricultural runoff. In scenarios involving bioaugmentation of a leachate lagoon, the dosages might be on the higher side due to elevated levels of organic pollutants in the leachate wastewater.

5. Factors Influencing Wastewater Bioaugmentation

There are several factors that influence wastewater bioaugmentation and its performance.

5.1 Application methodology

The application methodology involves direct dosing, where selected microorganisms are added directly to a treatment reactor, providing a straightforward and cost - effective bioaugmentation method as needed. However, challenges may arise from reduced survival rates due to a lack of acclimatization to the host environment. Installing a small side - stream reactor to acclimate the microorganisms before adding them to the main reactor can help overcome this challenge. [5] Once the application methodology is decided, selecting the right dosing location for bioaugmentation becomes crucial. It's advisable to examine the process flow diagram and key wastewater parameters to identify the optimal location. Bioaugmentation is best carried out in reactors with active biology, such as an activated sludge system. However, considering multiple dosing locations can enhance the retention time for biological treatment. In cases of insufficient retention time, bioaugmentation can also be done in the primary treatment stage, like in equalization or collection tanks. It's essential to ensure that ideal conditions for bacterial growth and performance are maintained when conducting bioaugmentation in the primary stages of treatment.

5.2 Temperature

Cold temperatures pose challenges for maintaining stable wastewater treatment operations in cold regions. [7] Bacteria can survive in different temperatures, and they are grouped based on their preferred growth conditions. There are three main types: psychrophiles like it cold, mesophiles prefer moderate temperatures, and thermophiles thrive in high temperatures. When talking about temperature, there are three terms to know: the minimum growth temperature (the lowest temperature where bacteria can grow), the maximum growth temperature (the highest temperature where bacteria can grow), and the optimum growth temperature (the temperature where bacteria grow the fastest). [8]

Table 3: Temperature Classification of Biological Processes [9]

Bacteria Type	Temperature Range (°C)	Optimum Temperature Range (°C)
Psychrophilic	10 - 30 °C	12 - 18 °C
Mesophilic	20 - 50 °C	25 - 40 °C
Thermophilic	35 - 75 °C	55 - 65 °C

Microorganisms in aerobic biological wastewater treatment systems typically fall within the mesophilic temperature range. [8] However, in extremely cold winter conditions in specific regions, mesophiles may struggle to perform actively. Depending on the operating conditions, the selection of bioaugmentation technology should be done with careful consideration.

Low wastewater temperature will certainly impact microbial metabolism and the removal of contaminants. Specifically, lower temperatures can result in the deterioration of physiological characteristics, a decrease in microbial growth rates, a decline in microbial activity, and changes in microbial community structure and sludge settleability. [10]

5.3 pH

pH is a crucial control parameter in sewage treatment, directly impacting the growth, metabolism of microorganisms, and activity of biological enzymes. The required pH values for wastewater treatment vary among microorganisms. Studies suggest that achieving a pH of 7 or higher enhances the removal efficiency of Ammonia Nitrogen and Total Phosphorus. Maintaining a pH between 6.4 and 7.0 inhibits ammonia - oxidizing bacteria activity and reduces N_2O production, with maximum N_2O production observed at a pH of 8.0. Proper pH adjustment is critical in wastewater treatment to ensure the effectiveness of biological activity in the biological treatment system and prevent negative effects. [11]

5.4 Nutrient Availability

Wastewater from various industries typically has high carbon content but low levels of nitrogen and phosphorus. For effective biological treatment, maintaining an ideal ratio of carbon, nitrogen, and phosphorus at 100: 5: 1 is crucial. However, industrial effluents often lack these proportions, necessitating the addition of external sources to enhance biological treatment effectiveness. Managing nutrient supply is vital, as insufficient amounts reduce treatment efficiency, while excessive amounts raise process expenses. Introducing undesirable nutrients into the effluent may require additional treatment and lead to compliance concerns. Therefore, careful nutrient management is essential for optimizing the treatment process and minimizing costs. The amounts of added phosphorus and nitrogen depend on the introduced carbon load, influenced by the concentration of organic substances in the wastewater. [12] Addition of nutrients to biological reactor to increase its efficiency is known as biostimulation. [5]

6. Conclusion

Bioaugmentation offers several benefits when strategically applied to industrial wastewater treatment plants. Careful observation and maintenance of specific operating parameters are crucial for achieving optimal efficiency in biological treatment. Although wastewater operators regularly encounter these challenges, increased awareness, and education on the significance of these factors can enhance overall wastewater treatment plant efficiency and assist industries in meeting discharge standards. In conclusion, commercially available bioaugmentation products present a promising solution with the inherent capacity to endure diverse operating conditions, including variations in pH and temperature. Nevertheless, exercising caution is crucial, and a comprehensive study or investigation is advised prior to the application of such products. While a specific combination of microorganisms may exhibit resilience in controlled laboratory settings, it remains uncertain whether the same results will be replicated at a full - scale operational level. Therefore, it is strongly recommended to conduct thorough full - scale trials under real operating conditions to accurately assess and realize the complete spectrum of benefits offered by bioaugmentation technology. Only through such empirical testing can the efficacy and reliability of bioaugmentation products be validated, ensuring their successful integration into practical applications.

References

[1] J. Boguniewicz - Zablocka, I. Klosok - Bazan, A. G. Capodaglio, and J. Ploskonka, “Planning the optimal solution for wastewater management in rural areas - case study, ” *MATEC Web of Conferences*, vol.174, p.01035, 2018, doi: https: //doi. org/10.1051/matecconf/201817401035.

[2] Edward D. Schroeder, Water Resources, Editor (s): Robert A. Meyers, Encyclopedia of Physical Science and Technology (Third Edition), Academic Press, 2003, Pages 721 - 751, ISBN 9780122274107, https: //doi. org/10.1016/B0 - 12 - 227410 - 5/00821 - 8.

[3] M. M. Ghangrekar, M. Behera, 3.5 - Suspended Growth Treatment Processes, Editor (s): Satinder Ahuja, Comprehensive Water Quality and Purification, Elsevier, 2014, Pages 74 - 89, ISBN 9780123821836, https: //doi. org/10.1016/B978 - 0 - 12 - 382182 - 9.00087 - 6.

[4] Lakshmi Machineni; Review on biological wastewater treatment and resources recovery: attached and suspended growth systems. *Water Sci Technol* 1 December 2019; 80 (11): 2013–2026. doi: https: //doi. org/10.2166/wst.2020.034

[5] E. Raper, T. Stephenson, D. R. Anderson, R. Fisher, and A. Soares, "Industrial wastewater treatment through bioaugmentation, " Process Safety and Environmental Protection, vol.118, pp.178–187, Aug.2018, doi: https: //doi. org/10.1016/j. psep.2018.06.035.

[6] R. Fuller, "Bioaugmentation, " the wastewater blog, Jan.02, 2019. https: //www.thewastewaterblog. com/single - post/2014/09/09/bioaugmentation

[7] D. Fang *et al.,* "Microbial community structures and functions of wastewater treatment systems in plateau and cold regions, " *Bioresource Technology*, vol.249, pp.684–693, Feb.2018, doi: https: //doi. org/10.1016/j. biortech.2017.10.063.

[8] Isnawati and G. Trimulyono, "Temperature range and degree of acidity growth of isolate of indigenous bacteria on fermented feed 'fermege, '" Journal of Physics: Conference Series, vol.953, p.012209, Jan.2018, doi: https: //doi. org/10.1088/1742 - 6596/953/1/012209.

[9] Metcalf, Wastewater engineering treatment and reuse. Mcgrawhill, 2013.

[10] H. Zhou, X. Li, G. Xu, and H. Yu, "Overview of strategies for enhanced treatment of municipal/domestic wastewater at low temperature, " Science of The Total Environment, vol.643, pp.225–237, Dec.2018, doi: https: //doi. org/10.1016/j. scitotenv.2018.06.100.

[11] H. Lan, H. Zhang, D. Yang, J. Liu, G. Tang, and H. Zhang, "Effects of pH on biological treatment of paper mill white water with the addition of dominant bacteria, " *BioResources*, vol.13, no.3, pp.6757–6765, Jul.2018, doi: https: //doi. org/10.15376/biores.13.3.6757 - 6765.

[12] "Nutrient Dosing for Wastewater Treatment - Real Tech Blog, " *Real Tech Water*, Jan.19, 2019. https: //realtechwater. com/blog - post/optimal - nutrient - dose - for - wastewater - treatment/