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Main Factors Affecting Microorganisms in the Water Treatment Process

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Abstract: *This article considers one of the biological treatment methods in water treatment processes - purification by microorganisms. This article considers the factors present in water that affect the growth, stability and death of microorganisms and their mathematical models. The effects of temperature, pH level, oxygen, water flow rate, substrates and inhibitors on these factors are mathematically considered and graphs are created and illustrated using examples.*

Keywords: *microorganisms, growth, death and stationary state of microorganisms, temperature, pH, oxygen, water flow rate, metabolism, optimal temperature, dissolved oxygen, substrates, inhibitors. Nitrogen, phosphorus, heavy metals.*

Introduction

Today, as a result of the high level of development of production and industry and other factors, a large part of the water resources on Earth are being polluted. Although our planet is 70% covered with water, not all of them are considered suitable for human consumption. Rapid industrialization, water consumption from scarce water resources, and many other factors play a significant role in water pollution. Every year, 400 billion tons of waste are generated worldwide. There are several methods for treating this water, one of which is biological treatment. Several types of microorganisms are usually used in the biological treatment process. Many factors in the water composition affect the activity of microorganisms. This can be both beneficial and harmful. For example, while temperature at its optimal value creates the most favorable conditions for the growth of microorganisms, excessive temperature is the main cause of their death. The remaining factors also have a similar effect. The following article considers mathematical models to find the optimal values of these factors.

pH Effect

For a biological treatment system, pH is an important environmental factor that can affect the activity of microorganisms. In general, the optimal pH for aerobic processes is around neutral pH (7-7.8), and for anaerobic processes, it is between 6.8-7.2. It is a difficult link in a biological treatment system to control due to its nonlinearity and large time lag.

pH affects the ionic properties of the bacterial cell, therefore it affects the growth of bacteria. Most bacteria grow at neutral pH (6.5-7.5). However, there are some bacteria that grow best at acidic or basic pH.

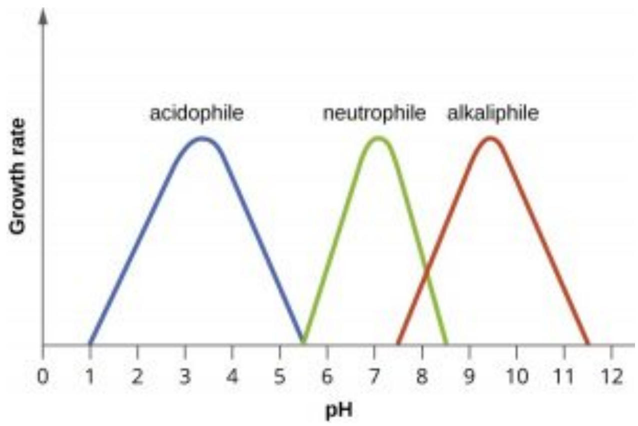

Figure 1. Types of microorganisms that grow at different pH values

pH is the negative logarithm of the hydrogen ion concentration. Microbial growth is strongly influenced by the pH of the environment. Abrupt changes in cytoplasmic pH disrupt the plasma membrane or inhibit the activity of enzymes and membrane transport proteins.

The basic growth model of Baranyi and Roberts (1994) is often used in predictive microbiology. This model is used here to establish a benchmark for comparison with other models. The equations are written using the natural logarithm of the cell density n and the natural logarithm of the physiological state q:

$$\frac{dn(t)}{dt} = \mu_{\max}(pH)\left(\frac{1}{\exp(-q(t)+1)}\right)(1-\exp(n(t)-n_{max}))\ (1)$$

Where $n(t = 0) = n_0$

$$\frac{dq(t)}{dt} = \mu_{\max}(pH)\ (2)$$

Where $q(t=0) = q_0$

where μ_{max} is the maximum specific growth rate at a given pH and n_{max} is the maximum cell density. The gamma factor, which represents the effect of the stationary phase, is based on the product factor of the P-model developed by Van Impe et al. (2005):

$$\frac{dN(t)}{dt} = \mu_{\max}(pH)\cdot\left(\frac{Q(t)}{Q(t)+1}\right)\cdot\left(1-\frac{P(t)}{K_p}\right)\cdot N(t)\ (3)$$

$N(t=0) = N_0$

$$\frac{dQ(t)}{dt} = \mu_{max}(pH)Q(t)\ (4)$$

$Q(t=0) = Q_0$

$$\frac{dN(t)}{dt} = Y_{\frac{P}{N}}\cdot\mu_{\max}\left(\frac{Q(t)}{Q(t)+1}\right)\cdot\left(1-\frac{P(t)}{K_p}\right)\cdot N(t)\ (5)$$

$P(t=0) = P_0$

Here N is the cell density, Q(t) is the dimensionless physiological state of the cell, P(t) is the concentration of growth-inhibiting metabolic products, KP is the maximum concentration of growth-inhibiting metabolic products, $Y_{P/N}$ is the yield of growth-inducing metabolic products

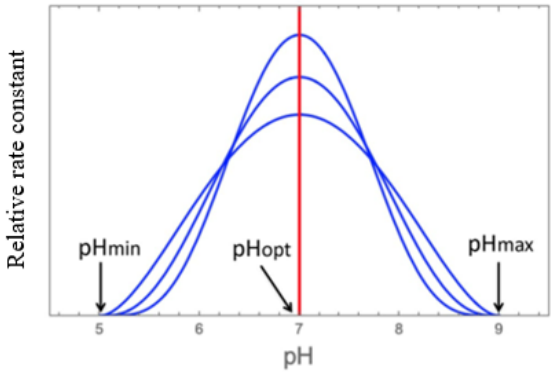

Figure 2. Effect on the growth of microorganisms

Effect of dissolved oxygen on microbial growth

In biological wastewater treatment, the effect of oxygen on microbial growth is a crucial factor that significantly affects the efficiency of the treatment process.

Oxygen is essential for aerobic biological processes in wastewater treatment. Microorganisms, primarily bacteria, use oxygen to decompose organic matter present in wastewater. The presence of dissolved oxygen (DO) in the treatment system determines the growth and activity of these aerobic microorganisms.

In aerobic wastewater treatment systems, such as activated sludge processes, an adequate supply of DO is essential. Oxygen supports the metabolic activity of aerobic bacteria, which convert organic pollutants into carbon dioxide, water, and biomass. Optimal DO levels promote the growth of beneficial bacteria that effectively degrade organic matter.

The DO concentration in the treatment system must be carefully controlled. Low DO levels can lead to incomplete decomposition of organic matter, while excessive DO can lead to excessive oxygenation, which can harm some microbial communities and increase operating costs.

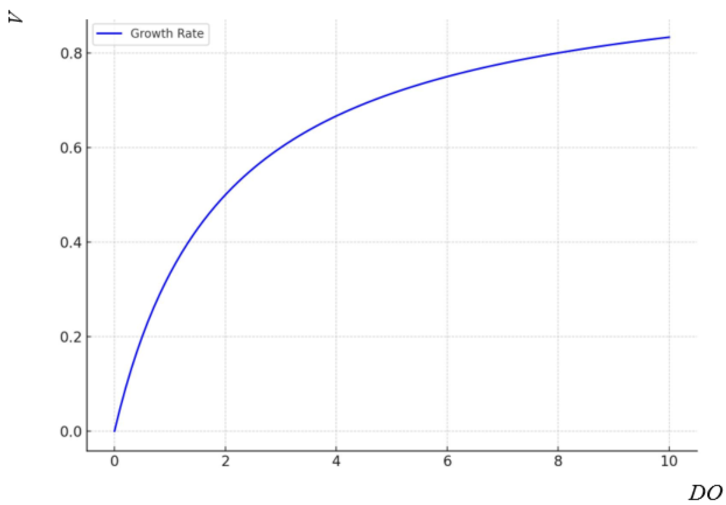

Figure 3. Relationship between microbial growth rate and dissolved oxygen concentration

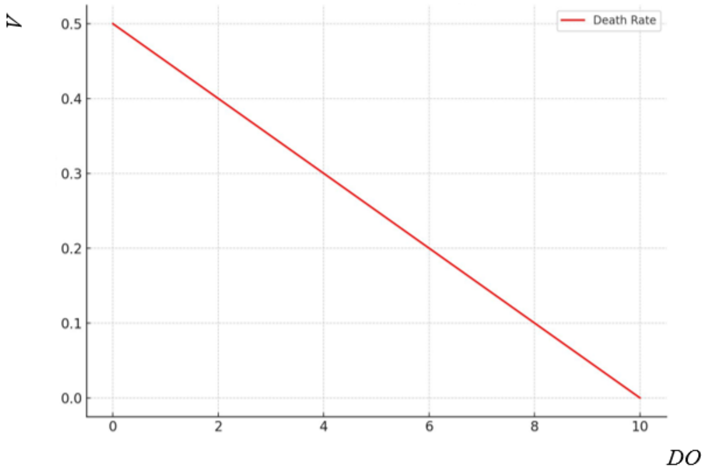

Figure 4. Graph of the relationship between dissolved oxygen and the growth and death of microorganisms

Similarly, the level of dissolved oxygen is an important factor affecting the efficiency of biological wastewater treatment. It affects parameters such as microbial growth rate and the activity of certain microorganisms. Therefore, maintaining an optimal balance of dissolved oxygen is important not only for the effective decomposition of organic matter and the prevention of odor, but also for optimizing the removal of nutrients and other key biological functions of the system.

Substrates and inhibitors affecting the growth of microorganisms

In wastewater, microorganisms primarily consume organic matter and nutrients as food sources. Their main components are:

Organic matter (carbon source): microorganisms in wastewater treatment systems feed primarily on organic compounds such as carbohydrates, proteins, fats and oils. These organic substances are broken down into simpler compounds, which microorganisms use for energy and growth.

$$\mu = \mu_{max} \cdot \frac{S}{K_S + S} \quad (6)$$

Where μ - Specific growth rate of the microorganism (per unit of time, e.g., per hour), μmax - Maximum growth rate (per unit of time), S - Concentration of the carbon source (mg/L), K_s - Concentration of the carbon source at which the half-saturation constant, the growth rate is half of μmax (mg/L)

Modified interpretation of the Monod equation

When the concentration of the carbon source is much lower than K_s, the growth rate is directly proportional to S.

The equation is simplified as follows:

$$\mu \approx \mu_{max} \cdot \frac{S}{K_S} \quad (7)$$

When the concentration of the carbon source is much higher than K_s, the growth rate approaches its maximum value μ_{max}.

The equation is simplified as follows:

$$\mu \approx \mu_{max}$$

If $S = K_s$, the growth rate is half of μ_{max}:

$\mu = \frac{\mu_{max}}{2}$ (8)

Nitrogen is an essential nutrient for microorganisms, usually in the form of ammonium (NH_4^+), nitrate (NO_3^-), or organic nitrogen compounds. Microorganisms use nitrogen to synthesize proteins, nucleic acids, and other cellular components.

$\mu = \mu_{max} \cdot \frac{N}{K_n + N}$ (9)

Where N is the concentration of the nitrogen source (e.g., ammonia or nitrate, mg/L), K_n is the half-saturation constant of nitrogen, the concentration at which the growth rate is half of μ_{max} (mg/L).

Phosphorus is another essential nutrient, often found in wastewater as phosphate (PO_4^{3-}). Microorganisms need phosphorus to produce nucleic acids, ATP (adenosine triphosphate), and phospholipids for cell membranes.

$\mu = \mu_{max} \cdot \frac{P}{K_p + S}$ (10)

Where P is the phosphorus concentration (mg/L). K_p is the half-saturation constant of phosphorus, the concentration at which the growth rate is half the μmax (mg/L).

Microorganisms require trace amounts of elements such as iron (Fe), magnesium (Mg), calcium (Ca), and potassium (K) for various enzymatic processes and cellular functions.

$\mu = \mu_{max} \cdot \frac{TE}{K_{te} + TE}$ (11)

TE is the concentration of the micronutrient (mg/L), K_{te} is the half-saturation constant for the micronutrient, the concentration at which the growth rate is half of μ_{max} (mg/L).

In the general process, all these nutrients can simultaneously affect the growth of microorganisms. The structure of their general model is as follows:

$$\mu = \mu_{max} \cdot \frac{S}{K_S + S} \cdot \frac{N}{K_n + N} \cdot \frac{P}{K_p + S} \cdot \frac{TE}{K_{te} + TE} \quad (12)$$

Here, S represents the carbon source, and the other terms represent nitrogen, phosphorus, and trace elements.

This integrated model shows how each nutrient acts as a limiting factor, and if any of these nutrients are deficient, the overall growth rate of microorganisms decreases.

Effect of Inhibitors

The presence of these inhibitors in wastewater can lead to a decrease in microbial activity. Toxic heavy metals such as copper (Cu), lead (Pb), mercury (Hg), cadmium (Cd), and zinc (Zn), organic compounds such as phenols, solvents, pesticides, and chlorinated hydrocarbons, high concentrations of ammonia (NH_3) and nitrite (NO_2^-), high concentrations of salts such as sodium chloride (NaCl), temperature, pH, and high oxygen values have a negative effect on the growth of microorganisms in water treatment processes. Several mathematical models are available to describe the effects of inhibitors. The most widely used of these is the modified Monod model. This model is usually used for non-competitive inhibitors:

$$\mu = \mu_{max} \cdot \frac{S}{K_S + S} \cdot \frac{1}{1 + \frac{I}{K_i}} \quad (13)$$

Here I - Inhibitor concentration (mg/L), K_i - Inhibition constant, the inhibitor concentration at which the growth rate is halved (mg/L).

The following model is used to describe the growth of microorganisms under the influence of competitive inhibitors:

$$\mu = \mu_{max} \cdot \frac{S}{K_S\left(1+\frac{I}{K_i}\right)+S} \quad (14)$$

In this model, the presence of an inhibitor increases the apparent half-saturation constant Ks, meaning that a higher substrate concentration is required to achieve the same growth rate without the inhibitor.

In the general case, the following model can be used:

$$\mu = \mu_{max} \cdot \frac{S}{K_S+S} \cdot \frac{1}{\sum \frac{I}{K_{i,j}}} \quad (15)$$

Conclusion

Microorganisms play a critical role in wastewater treatment for the effective removal of organic pollutants. Mathematical modeling of factors affecting microbial growth can help optimize the treatment process. Important factors such as temperature, dissolved oxygen concentration, nutrient availability (e.g., phosphorus, nitrogen, and trace elements), and water flow rate have a significant impact on microbial activity and pollutant degradation efficiency.

Mathematical models such as the Monod equation provide an understanding of how substrate concentration affects microbial growth rates and help predict operational efficiency under different conditions. Arrhenius-type models effectively describe the effect of temperature on microbial kinetics, identifying optimal conditions for maximum biological activity. In addition, the effect of dissolved oxygen is modeled through saturation kinetics, suggesting a way to maintain aerobic conditions for optimal microbial respiration. The water flow rate, which affects microbial retention time and substrate contact, is often modeled through flow regime analysis and directly affects the performance of biological treatment systems.

By integrating these mathematical expressions into the design and operation of wastewater treatment plants, engineers can improve system efficiency, predict potential problems, and design treatment processes that maximize pollutant removal while minimizing energy consumption and operating costs. The development and application of these models are critical to improving the sustainability and efficiency of modern water treatment systems.

In summary, mathematical expressions that reflect the interactions between environmental factors and microbial processes are key to optimizing biological wastewater treatment. These models are invaluable tools for improving efficiency, making operational decisions, and ensuring that water treatment systems operate at their highest potential.

Literatures:

1. Ahmedov, D. AVTOMOBIL BATAREYALARINI AVTOMATIK NAZORAT QILISH LOYIHASINI ISHLAB CHIQISH. https://cyberleninka.ru/article/n/avtomobil-batareyalarini-avtomatik-nazorat-qilish-loyihasini-ishlab-chiqish
2. Mannobjonov, B. Z., & Azimov, A. M. (2022). NEW INNOVATIONS IN GREENHOUSE CONTROL SYSTEMS & TECHNOLOGY. *Экономика и социум*, (7 (98)), 95-98. https://cyberleninka.ru/article/n/new-innovations-in-greenhouse-control-systems-technology

3. Mannobjonov, B., & Azimov, A. (2022). NUTRIENTS IN THE ROOT RESIDUES OF SECONDARY CROPS. *Экономика и социум*, (6-2 (97)), 126-129. https://cyberleninka.ru/article/n/nutrients-in-the-root-residues-of-secondary-crops-1
4. Mannobjonov, B. Z., & Azimov, A. M. (2022). THE PRODUCE FRESHNESS MONITORING SYSTEM USING RFID WITH OXYGEN AND CO2 DEVICE. *Экономика и социум*, (7 (98)), 92-94. https://cyberleninka.ru/article/n/the-produce-freshness-monitoring-system-using-rfid-with-oxygen-and-co2-device
5. АГРЕГАТ, Д., & ТРАНСФОРМАТОРОВ, С. (2021). Universum: технические науки: электрон. научн. журн. *Ismailov A. I, Shoxruxbek B, Axmedov D, Mannobjonov B*, *12*, 93.
6. Исмаилов, А. И., Бахрамов, Ш. К. У., Ахмедов, Д. М. У., & Маннобжонов, Б. З. У. (2021). АГРЕГАТ ДЛЯ ИЗГОТОВЛЕНИЯ РЕЗИНОВЫХ УПЛОТНИТЕЛЕЙ МАСЛЯНЫХ СИЛОВЫХ ТРАНСФОРМАТОРОВ. *Universum: технические науки*, (12-6 (93)), 26-28. https://cyberleninka.ru/article/n/agregat-dlya-izgotovleniya-rezinovyh-uplotniteley-maslyanyh-silovyh-transformatorov
7. Mannobjonov, B. Z. Mashrabov Sh. D.(2022). Using Android Mobile Application for Controlling Green House. *Texas Journal of Engineering and Texnology*, 2770-4491.
8. Mannobjonov, B. Z., & Azimov, A. M. (2022). NEW INNOVATIONS IN GREENHOUSE CONTROL SYSTEMS & TECHNOLOGY. *Экономика и социум*, (7 (98)), 95-98. https://cyberleninka.ru/article/n/new-innovations-in-greenhouse-control-systems-technology
9. Mannobjonov, B. Z., & Azimov, A. M. (2022). THE PRODUCE FRESHNESS MONITORING SYSTEM USING RFID WITH OXYGEN AND CO2 DEVICE. Экономика и социум,(7 (98)), 92-94.
10. Boburbek, M., Oyatillo, A., & Diyorbek, M. (2023). AUTOMATION OF WATER TREATMENT PROCESSES: ENHANCING EFFICIENCY AND SUSTAINABILITY. *FAN, JAMIYAT VA INNOVATSIYALAR*, *1*(5), 24-29.
11. Boburbek, M., Oyatillo, A., & Diyorbek, M. (2023). AUTOMATION OF WATER TREATMENT PROCESSES: ENHANCING EFFICIENCY AND SUSTAINABILITY. *FAN, JAMIYAT VA INNOVATSIYALAR*, *1*(5), 24-29.
12. Boburbek, M., Oyatillo, A., & Diyorbek, M. (2023). HYDROHARVEST: A PARADIGM SHIFT IN PLANT CARE THROUGH AUTOMATED WATERING SYSTEMS. *FAN, JAMIYAT VA INNOVATSIYALAR*, *1*(5), 19-23.
13. Zokirjon o'g'li, M. B. (2023). AUTOMATION OF WASTEWATER TREATMENT PLANTS: ENHANCING EFFICIENCY AND ENVIRONMENTAL SUSTAINABILITY. *Mexatronika va robototexnika: muammolar va rivojlantirish istiqbollari*, *1*(1), 354-357.
14. Zokirjon o'g'li, M. B. (2023). CLARIFYING WASTEWATER: A MICROBIOLOGICAL APPROACH. *Mexatronika va robototexnika: muammolar va rivojlantirish istiqbollari*, *1*(1), 379-385.
15. Mannobjonov, B. Z., & Azimov, A. M. (2022). THE PRODUCE FRESHNESS MONITORING SYSTEM USING RFID WITH OXYGEN AND CO2 DEVICE. *Экономика и социум*, (7 (98)), 92-94. https://cyberleninka.ru/article/n/the-produce-freshness-monitoring-system-using-rfid-with-oxygen-and-co2-device

16. Zokmirjon o‘g‘li, M. B., & Alisher o‘g‘li, A. O. (2023). BIOTECH DRIVES THE WATER PURIFICATION INDUSTRY TOWARDS A CIRCULAR ECONOMY. *Open Access Repository*, *4*(03), 125-129. https://www.oarepo.org/index.php/oa/article/download/2513/2488
17. Zokmirjon o‘g‘li, M. B. (2023). IFLOSLANGAN SUVLARNI BIOTEXNOLOGIK USUL BILAN TOZALASH. *Innovations in Technology and Science Education*, *2*(7), 1243-1258. https://humoscience.com/index.php/itse/article/download/489/862
18. Zokirjon o'g'li, M. B., & Muhammadjon o'g'li, O. O. (2022). MODELLING AND CONTROL OF MECHATRONIC AND ROBOTIC SYSTEMS. https://academicsresearch.ru/index.php/iscitspe/article/view/726
19. Zokirjon o’g’li, M. B., & Davronbek o’g’li, M. S. (2022). Using Android Mobile Application for Controlling Green House. *Texas Journal of Engineering and Technology*, *9*, 33-40. https://www.zienjournals.com/index.php/tjet/article/download/1873/1565
20. Mannobjonov, B., & Azimov, A. (2022). NUTRIENTS IN THE ROOT RESIDUES OF SECONDARY CROPS. *Экономика и социум*, (6-2 (97)), 126-129. https://cyberleninka.ru/article/n/nutrients-in-the-root-residues-of-secondary-crops-1
21. Исмаилов Астан Ибрагимович, Бахрамов Шохрухбек Козимжон Угли, Ахмедов Дурбек Мадаминжон Угли, Маннобжонов Бобуржон Зокиржон Угли АГРЕГАТ ДЛЯ ИЗГОТОВЛЕНИЯ РЕЗИНОВЫХ УПЛОТНИТЕЛЕЙ МАСЛЯНЫХ СИЛОВЫХ ТРАНСФОРМАТОРОВ // Universum: технические науки. 2021. №12-6 (93). URL: https://cyberleninka.ru/article/n/agregat-dlya-izgotovleniya-rezinovyh-uplotniteley-maslyanyh-silovyh-transformatorov
22. АГРЕГАТ, Д., & ТРАНСФОРМАТОРОВ, С. (2021). Universum: технические науки: электрон. научн. журн. *Ismailov A. I, Shoxruxbek B, Axmedov D, Mannobjonov B*, *12*, 93.
23. Mannobjonov, B. Z. Mashrabov Sh. D.(2022). Using Android Mobile Application for Controlling Green House. *Texas Journal of Engineering and Texnology*, 2770-4491.