Application of Artificial Wetlands in Water Pollution

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Abstract. With the development of social economy, a large number of pollutants such as heavy metals enter water bodies. Artificial wetlands have emerged with unique advantages in removing water pollutants, like removing the phosphorus or sodium, especially suitable for developing countries. Wetland aquatic plants have a large biomass and high organic content. Using aquatic plants as raw materials for anaerobic fermentation can not only produce biogas as bioenergy, but also achieve effective disposal of aquatic plants, avoiding secondary pollution and waste of biomass resources. Based on previous research on anaerobic fermentation of aquatic plants, this article explains the two reaction mechanisms of anaerobic digestion and their applications in constructed wetlands.

Keywords: Artificial wetlands, water treatment, mechanism, application.

1. Introduction

As one of the three major ecosystems in the world, wetlands are divided into natural and artificial type, perennial or seasonal waterlogged areas and water bodies which have important ecological functions, including waters with a depth of no more than six meters at low tide. 6% of the world's wetlands cover 40% of the world's wildlife, providing habitats, and over 1 billion people rely on wetlands for their livelihoods.Wetlands mainly include three types: inland wetlands, coastal and nearshore wetlands, and artificial wetlands. Inland wetlands mainly refer to swamps, lakes, rivers, peatlands, and groundwater habitats mainly composed of woody and herbaceous plants. Coastal and coastal wetlands mainly refer to coral reefs, mangroves, seaweed meadows, and estuaries. Artificial wetlands mainly refer to rice fields, dams, reservoirs, and fish ponds. The evaluation results of the Millennium Ecosystem Assessment (MA) project indicate that wetlands have a significant contribution to improving human well-being and reducing poverty. Wetlands can provide humans with extremely important fish resources, freshwater resources, genetic resources, as well as fiber, fuel, and biochemical substances. In terms of regulating services, wetlands have the functions of purifying water sources, harmless treatment of waste, regulating climate, mitigating natural disasters, and controlling erosion. In terms of support services, wetlands have the functions of retaining sediment, accumulating organic matter, and storing, processing, and obtaining nutrients, thus promoting the normal operation of soil formation and nutrient cycling.[1].

With the growth of population and economic development, humans continue to carry out large-scale development of wetlands. However, due to climate change, water pollution, and human activities such as agricultural activities and lake reclamation, global wetlands are facing severe situations such as biodiversity loss, eutrophication of water bodies, and area reduction. Due to the gradual reduction and extinction of natural wetlands in cities, artificial wetlands have received increasing attention and development due to their unique advantages.

This artical will introduce the two reaction mechanisms and applications of constructed wetlands.

2. Working Principle

According to different water flow patterns, artificial wetland sewage treatment systems have three different types, which are surface flow artificial wetlands and subsurface flow artificial wetlands. Surface flow constructed wetlands are similar to natural wetlands in that sewage flows over the surface of the wetland. These types of constructed wetlands have a simpler structure and lower

engineering costs, but they occupy a larger area and have limited sewage removal capacity; And due to the overflow of sewage on the surface of the filler, it is easy to breed mosquitoes and flies, which can have adverse effects on the surrounding environment. In subsurface flow constructed wetlands, sewage enters the filling bed from one end of the wetland and flows through the gaps between the filling beds through horizontal or vertical subsurface flow. This can fully utilize the adsorption and interception effects of the filling surface, rich plant roots, and biofilms on plant roots, achieving higher nitrogen and phosphorus removal effects. On the other hand, because of the flow of water below the surface of the wetland, the treatment effect is less affected by climate fluctuations, and drier habitats are suitable for the growth of mesophytes, with better hygiene conditions.

In recent years, composite constructed wetlands have been developed based on different sewage treatment purposes, which connect one or more surface flow constructed wetlands with one or more subsurface flow constructed wetlands in series or parallel, which is conducive to the occurrence of nitrification and denitrification and achieves better nitrogen removal effects.

2.1. Anaerobic Digestion

Anaerobic digestion is a complex metabolic process involving multiple facultative and specialized anaerobic microorganisms, based on complex organic matter as a substrate. There is an interaction between matrix chains and biological chains during anaerobic digestion. Anaerobic biological treatment of wastewater involves anaerobic microorganisms decompressing complex inorganic compounds in the absence of oxygen and other oxides, converting them into simple stable inorganic compounds and releasing energy. Methane and carbon dioxide as well as N_2, H_2, NH_3, and H_2S.

The anaerobic decomposition of organic matter is a complex biochemical reaction involving multiple microbial physiological groups. A large number of scholars have studied the metabolic pathways of different nutrient functional microbial communities and the shapes of different microorganisms at different stages of biochemical processes.

Based on the metabolic differences of microbial physiological groups, the theory of "three stages and four microbial communities" is currently widely accepted. It proposes that anaerobic digestion is completed under the action of four microbial communities (hydrolysis bacteria, bacteria produced by hydrogen acetic acid, bacteria produced by homotypic acetic acid, and bacteria produced by methane). The process can be divided into three stages.

2.1.1. Acidification

The first stage is hydrolytic fermentation (also known as acidification). In this stage, complex organic compounds such as carbohydrates, proteins, and lipids are experienced a process of fermentation into organic acids, alcohols, CO_2, H_2, NH_3, and H_2S through the metabolic activity of facultative hydrolytic fermentation bacteria (i.e. acid-producing bacteria).

2.1.2. Hydrogen and Acetic Acid Production

The second stage is the production of hydrogen and acetic acid. At this stage, the metabolic products of the first stage bacteria-propionic acid like some kinds of fatty acids, alcohols, and certain aromatic acids – are mainly converted into acetic acid, CO, and H through the physiological activities of the anaerobic hydrogen producing acetic acid producing bacteria.

2.1.3. Methane Production

The third stage is the methane production stage. Mainly, methane producing bacteria utilize acetic acid, CO_2, H_2 (as well as formic acid, methanol, and methylamine) produced in the first and second stages as the main substrate, ultimately converting into CH and CO_2. Methanogenic bacteria include two types of bacteria with strong specificity. A group of methane producing bacteria mainly use H to reduce CO to CH (which can also use formic acid). Another group of methane producing bacteria mainly use acetic acid as a substrate (methanol and methylamine can also be used) to decompose it into CH and CO_2. At this stage, according to research, there is another type of acetic acid producing bacteria that can convert CH. Synthesized with CO_2 to form acetic acid.

Anaerobic digestion is a multi group and multi-level mixed fermentation process. In this complex system, bacterial populations are interdependent, interdependent, and mutually constrained, and there is also a dynamic balance between their metabolites within the system.

2.2. Influence factors

In the following sections will explain some factors that affect anaerobic reactions, including redox potential, temperature, and pH value.

2.2.1. Oxidation-reduction potential

Oxygen is an oxidizing substance that is rejected in anaerobic fermentation systems. The presence of a very small amount of oxygen can poison the growth of methane bacteria.The oxidation-reduction potential (OPR) in anaerobic systems can represent the oxygen concentration in anaerobic reactors, which has a significant impact on methane bacteria. There are many enzyme systems with low redox potential in methane bacteria cells. When the standard potential of the oxidizing substances in the system is high and the concentration is high, these enzyme systems will be irreversibly oxidized and destroyed by high potential, causing the growth of methane bacteria to be inhibited or even killed.

It is generally believed that methane bacteria participating in moderate temperature digestion require an oxidation-reduction potential maintained in the environment below -350mV. For methane bacteria involved in high-temperature digestion, it should be below -600~-500mV. [1]

2.2.2. Tempperature

According to the adaptability range of methane bacteria to temperature, methane bacteria can be divided into three categories: low-temperature bacteria, mesophilic bacteria, and high-temperature bacteria. The adaptation range of low-temperature bacteria is 20-25 ℃, mesophilic bacteria are 30-45 ℃, and high-temperature bacteria are 45-75 ℃. After identification, there are fewer low-temperature bacteria among methane bacteria, most of which are mesophilic bacteria, and there are also many types of high-temperature bacteria. The influence of temperature on methane bacteria is much greater than that of acid producing bacteria, which is clearly manifested in three aspects by affecting the growth and reproduction speed inside cells, methane production, and external environmental conditions of cells. In fact, within the temperature range mentioned, there is no special temperature limit for methanogens. However, after being domesticated within a certain temperature range, any mild increase or decline in temperature (± 2 ℃) severely affects the progress of digestion, especially the sensitivity of high-temperature digestion to temperature changes.

2.2.3. pH value

During anaerobic treatment, both hydrolysis bacteria and acid producing bacteria have a great adaptability to pH values, and their pH values also have a significant impact on the growth of methane bacteria. The impact is manifested in the following aspects: affecting the physiological function and activity of the bacterial and enzyme systems; The redox potential that affects the environment by affects the availability of the matrix. The optimal pH range for most mesophilic methane bacteria is around 6.8 to 7.2, but there are also differences in the optimal pH values for various methane bacteria, ranging from 6.0 to 8.5.

2.2.4. Nutrients

In addition to the demand for nitrogen and phosphorus, anaerobic microorganisms also require sulfur as a component of microbial metabolism, but the required amount is relatively small. Compared with aerobic processes, anaerobic processes greatly reduce the synthesis of organisms, resulting in a corresponding reduction in the demand for other nutrients. It is generally believed that the ratio of organic substance to nitrogen and phosphorus in anaerobic processes is COD: N: P of 200:5:1.

2.2.5. Metabolic time

In order to ensure metabolic effects, sufficient contact time (HRT) is required for biological treatment, and the required metabolic time is related to the properties of the substrate. Simple low

molecular weight VFA, sugars, and ethanol can be metabolized in a short time, while big, complex, or chlorinated chemicals take hours or even days. Attention must be paid to ensuring sufficient time for organic matter metabolism during the anaerobic reaction process. In addition, the influencing factors of anaerobic reaction include trace elements, toxins and so on.

3. Application

3.1. Nitrogen Removal in Waste Water using Constructed Wetlands

The nitrogen in artificial wetlands is removed through microbial ammonification, nitrification, and denitrification, plant absorption, substrate adsorption, filtration, and sedimentation. Among them, ammonification, nitrification, and denitrification are the main ways to remove nitrogen, and their basic conditions are the presence of a large number of ammonifying bacteria, nitrifying bacteria, denitrifying bacteria, and appropriate wetland soil environmental conditions in the wetland.

Ammonia nitrogen can be directly ingested by plants, synthesized into plant proteins and organic nitrogen, and then removed from wetland systems through plant harvesting. The oxygen transport and transfer characteristics of wetland plant root hairs continuously present aerobic, anoxic, and anaerobic states around the root system, equivalent to many series or parallel processing units, allowing nitrification and denitrification to occur simultaneously in the wetland system.

3.2. Phosphorus

Some people mistakenly believe that wetlands only remove phosphorus through the adsorption process of existing soil. It is well known that soil has the ability to adsorb phosphorus, but this storage capacity is quickly saturated with an increase in phosphorus load. The research by Yuan et al. shows that the order of phosphorus saturation adsorption capacity from large to small is slag, fly ash, vermiculite, yellow brown soil, xiashu, loess, zeolite, sand. From the morphology transformation of adsorbed phosphorus, the result shows that the phosphorus adsorbed by yellow brown soil, Xiashu loess, and vermiculite is mainly converted into Fe-P, while sand, zeolite, fly ash, and slag are mainly converted into Ca-P. The higher the content of free iron oxide, colloidal iron oxide, and aluminum in the matrix, the more fixed forms of iron phosphate and aluminum phosphate are present, and the stronger the matrix's ability to purify phosphorus. Under experimental conditions, the phosphorus released by these fillers after adsorption saturation was less than 11% of the saturation amount. Li et al.'s study showed that the isothermal adsorption tests of phosphorus on three types of fillers showed that the maximum adsorption capacities of zeolite, gravel, and soil for PO_4^{3-} were 0.03, 0.107, and 1.11 mg/g, respectively [3-5].

3.3. Sedimentation

The phosphorus deposition in wetlands refers to the soluble phosphate in the influent water. The process by which salt causes phosphorus to be stored inside wetlands through physical processes. Multiple studies have shown that sediment/coal seams are the main source of phosphorus in wetlands. Compared to terrestrial ecosystems, wetlands are not a long-term source of phosphorus effective exchange. Sediments - Litter and fallen leaves are the main source of natural wetlands (over 95%) phosphorus storage site.

The degree of inorganic soil P adsorption is related to the levels of Al, Fe, and Ca, and the capacity of P’s adsorpation of wetland soil can be predicted by the amount of oxalate extractable aluminum in the soil. The phosphorus storage capacity of soil increases with the increase of organic matter content. The P adsorption capacity of minerals is better than that of organic soil. Dierberg et al. found that direct plant absorption and co precipitation can quickly and almost completely remove SRP from agricultural runoff [6,7].

3.4. Microbial Absorption and Excessive Accumulation

All microorganisms contain a certain amount of phosphorus, usually accounting for ash content 30% to 50% of the total amount (calculated as P_2O_5). Phosphorus is the main component in microbial cells. It should exist in nucleic acids, nucleotides, phospholipids, and other phosphorus containing compounds. Wall acid and polyphosphate are the main phosphorus compounds. In bacteria, yeast polyphosphates are present in both fungal and algal cells.

The effects of microorganisms on phosphorus include normal absorption and excessive accumulation. In wetlands, the assimilation of phosphorus by microorganisms mainly occurs in fillers (such as soil). The assimilation of photosynthetic microorganisms requires high degree of water temperature and abundent sunlight. The assimilation of heterotrophic organisms requires an appropriate amount of organic carbon source. Both autotrophic and heterotrophic assimilation require effective inorganic nitrogen sources.

3.5. Plant Absorption

Soluble phosphates (HPO_4^{2-} and H_2PO^{4-}) are absorbed by plant roots and assimilated into organic components of plants (like ATP, phospholipids, coenzymes, RNA, and DNA). As shown in Fgi.1. The phosphorus intake of large plants is lower than the nitrogen intake because the mass fraction of phosphorus in plant tissues is much lower than the mass fraction of nitrogen. Therefore, it is hoped that plants that assimilate and store phosphorus should have the ability to grow rapidly, have high tissue phosphorus content, and achieve high yields.

Harvesting large plants helps to remove phosphorus from wetlands. If not harvested, phosphorus is released back into the system after the plant dies. The dissolution release experiments of commonly used plants such as reed, water bamboo, and water hyacinth in wetlands and ponds showed that under the conditions of a retention time of 5 days, hydraulic load of 8.7 cm/d, and TN, TP, and COD loads of 1.52, 0.11, and 13.7 g/(m^2 d), the amount of N, P, and COD released by plant tissues accounted for 29%, 20%, and 38% of the removal load, [8,9]respectively. The phosphorus content in the aboveground part of plants is higher than that in the underground part, because nutrients are transferred from the aboveground part to the underground part during the plant decay period. Therefore, harvesting before the plant decay period (such as October and November) can increase the amount of phosphorus carried out of the system due to plant harvesting compared to harvesting in January. Harvesting in the early summer (such as June) may lead to the long-term vitality of the plant in the following years. Research on wetlands for treating farm wastewater (with an area of 19 square meters and influent water quality of TN, 10-110 g m^{-3}; NH_4^+- N, 5-70 g m^{-3}; TP, 8-18 g m^{-3}) has shown that in the first year of monitoring, the phosphorus removal rate of plant-based wetlands is 3% to 60% higher than that of plantless wetlands. Under the condition of moderate influent load (P335 kg·hm^{-2}) in vertical flow wetlands, the phosphorus removal amount by plant harvesting accounts for 10% of the influent phosphorus amount. The potted experiment treated artificial water distribution, with a phosphorus loading of P 1.1 g m^{-2} week-1 and a phosphorus mass concentration of 50 mg L^{-1} in the influent. The phosphorus removal rate of plant harvesting was lower than 5% of the total phosphorus in the system. In artificial wetlands that treat mildly eutrophic water, plant absorption makes a big impact in the removal of phosphorus, which with a contribution rate of 51.0% [10-12]. There is a significant correlation between the accumulation of phosphorus in plants and the quality concentration and biomass of incoming water. Therefore, the ratio of plant harvesting phosphorus removal to total wetland phosphorus removal depends on the frequency and period of plant harvesting, inflow load, wetland effluent quality requirements, plant species (biomass and plant).

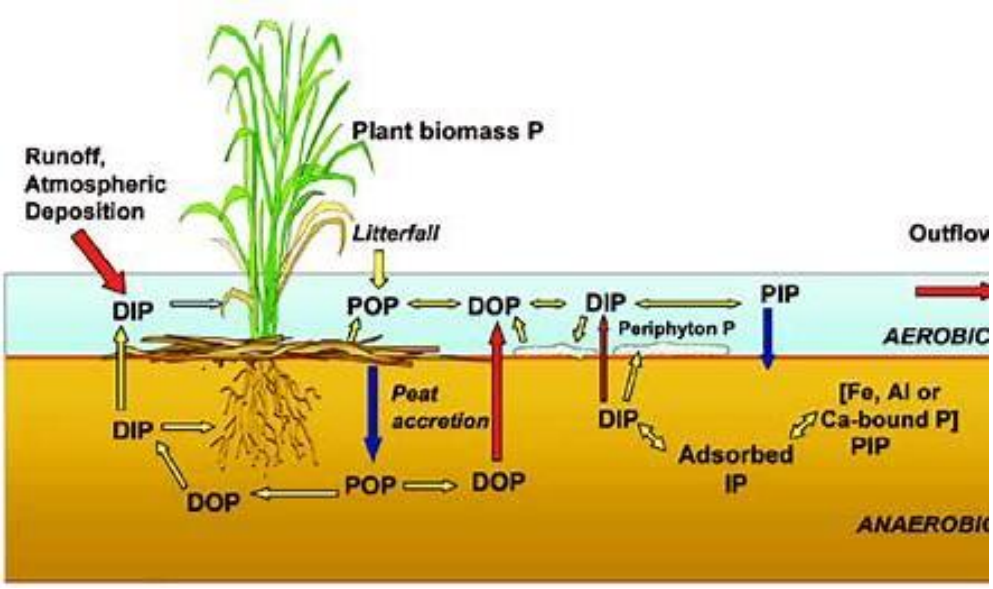


Figure 1. The chemicals in the wetland

4. Summary

The regularity of the contribution of mechanisms like adsorption, sedimentation, plant absorption, microbial absorption and accumulation to phosphorus removal in wetland systems needs to be summarized in more research. Further research is needed on the conditions under which plant harvesting related to long-term phosphorus removal in wetlands should be carried out, including climate, water inflow load, and harvesting frequency. Adsorption (adsorption sites mainly provided by substrates and plants) is one of the major mechanisms of the removal of phosphorus in wetlands, and adsorption sites decrease with the increase of accumulated water inflow; There is still a lack of understanding of the most effective way to remove available phosphorus from water columns or soil pore water, making it difficult to predict the process of desorption or release of unavailable phosphorus into soluble phosphorus in the environment. Therefore, long-term effective phosphorus removal in wetlands is an urgent problem to be solved. The contact opportunity between sewage and fillers is an important factor in wetland phosphorus removal. Suitable fillers (such as fillers rich in iron and aluminum) can be selected in subsurface wetlands to enhance phosphorus removal performance. Developing and selecting production waste with strong phosphorus removal capabilities not only effectively removes phosphorus but also has significant economic benefits. Dry wet alternation can promote changes in redox potential and oxygen mass concentration in the surrounding environment of microorganisms. It is necessary to determine a reasonable dry wet alternation cycle that contributes to long-term effective phosphorus removal in wetlands based on the inflow load, wetland structure, and climate conditions.

References

[1] Lu Shaoyong, Jin Xiangcan & Yu Gang (2006). Mechanism of phosphorus removal in constructed wetlands Ecological Environment (02), 391 - 396. doi: 10.16258/j.cnki.1674 - 5906. 2006. 02. 040.

[2] Liang Jinming, Li Jie, Wang Ya'e. Application status and prospects of artificial wetlands in northwest China. Water Treatment Technology, 2022, 48 (12): 13 - 18.

[3] Kadlec R H. Overview: Surface flow constructed wetlands. Water Science Technology, 1995, 32 (3): 1 - 12.

[4] Yuan D H, Jin L H, Zhang M Q, et al. Mechanism of phosphorus purification in some kinds of substrates constructed wetland systems. China Environmental Science, 2004, 24 (5): 614 - 617.

[5] Li X D, Zhou Q, Zhang R S. A comparative study on nitrogen and phosphorus removal performance for three types of constructed wetlands. Earth Science Frontiers, 2005, 12: 73 - 76.

[6] Pan J H, He Y, Deng W, et al. Progress in the study on the function of wetland in removal phosphorus in water. Ecology and Environment. 2004, 13 (1): 102 - 104.

[7] Dierberg F E, DeBusk T A, Jackson S D, et al. Submerged aquatic vegetation-based treatment wetlands for removing phosphorus from agricultural runoff: response to hydraulic and nutrient loading. Water Research, 2002, 36 (6): 1409 - 1422.

[8] Kim S Y, Geary P M. The impact of biomass harvesting on phosphorus uptake by wetland plants. Water Science & Technology, 2001, 44 (11-12): 61 - 68.

[9] Tanner C C, Clayton J S, Upsdell M P. Effect of loading rate and planting on treatment of dairy farm wastewaters in constructed wetlands-II. Removal of nitrogen and phosphorus. Water Research, 1995, 29 (1): 27 - 34.

[10] Lu S Y, Zhang P Y, Yu G, et al. The contaminants release rule of Zizania caduciflora, Phragmites austrails and Eichhornia crassipes. China Environmental Science, 2005, 25 (5): 554 - 557.

[11] Meuleman Arthur F M, van Logtestijn Richard, Rijs Gerard B J, et al. Water and mass budgets of a vertical-flow constructed wetland used for wastewater treatment. Ecological Engineering, 2003, 20 (1): 31 - 44.

[12] Jiang Y P, Ge Y, Yue C L, et al. Nutrient removal role of plants in constructed wetland on sight seeing water. Acta Ecologica Sinica, 2004, 24 (8): 1718 - 1723.