Research on performance improvement of constructed wetland wastewater treatment system

Yuting Mao *, Haiqin Huang *

Office of Mountain-River-Lake Development Committee of Jiangxi Province, Nanchang, 330046, China

*Corresponding author e-mail: mydomimi@qq.com, *491615712@qq.com

Abstract. Constructed wetland is a kind of wastewater ecological treatment technology. It has the advantages of low investment, convenient operation and management, stable water quality, and has certain landscape effects. Therefore, it is widely used in the field of wastewater treatment. However, this technology still has certain problems in practical engineering applications, such as irregular design and clogging, resulting in limited service life and processing performance of the wetland. The type selection of constructed wetlands, matrix type and particle size, plant type and configuration, and water inflow mode and operating parameters are the main factors affecting the operating life and purification effect of constructed wetlands. Based on the author's practice, the article introduces in detail the current process structure, basic design methods and economic and technical comparison of constructed wetland wastewater treatment for reference by relevant scientific research and design units.

Keywords: Constructed wetland; wastewater treatment system; Engineering design; System performance.

1. Research background

Constructed wetland is a kind of artificially constructed and supervised ground similar to natural wetlands. It artificially constructs one or several mediums such as stone, sand and soil into a matrix in a certain proportion and selectively implants plants. wastewater treatment ecosystem. Because of the advantages of good treatment effect, low construction and operation cost, and easy maintenance and management [1], the constructed wetland has received universal attention from all over the world and has become a new wastewater treatment technology that has developed rapidly in recent years [2]. The research on artificial wetland process design is the premise and foundation of constructing constructed wetland. It has always been the focus of research on constructed wetland treatment technology. This paper mainly describes the research progress and future research ideas of artificial wetland treatment system process design.
2. Process analysis

2.1. Basic types of constructed wetland systems

According to the difference between engineering design and water flow, the constructed wetland wastewater treatment system can be divided into three main types: surface flow wetland, horizontal subsurface wetland and vertical flow wetland. There are some differences in the characteristics of operation and control of each type [3], as shown in Table 1. Among them, the surface wetland does not require gravel or the like as a matrix, and the cost is low, but the hydraulic load is low. This type has more distribution in the United States, Canada, New Zealand, Sweden and other countries; the horizontal submerged wetland has better moisture retention, BOD, Organic matter and heavy metals such as COD have good removal effects and are less affected by the seasons. Currently, they are widely used in Europe and Japan. Vertical flow wetlands combine the characteristics of the former two, but their construction requirements are relatively high and have not been widely used.

| Characteristic Parameters | Surface wetland | Horizontal subsurface wetland | Vertical flow wetland |
|---------------------------|-----------------|-------------------------------|-----------------------|
| Hydraulic flow            | Surface flow    | Horizontal flow under the matrix | The surface flows longitudinally toward the bottom of the substrate |
| Hydraulic load            | Lower           | Higher                         | Higher                |
| Decontamination effect    | General         | Good removal effect on BOD, COD and heavy metals | Good removal effect on N and P |
| System control            | Simple, affected by the season | Relatively complex | Relatively complex |
| Environmental condition   | Stinking season, easy to breed mosquitoes | good | Stink in summer, easy to breed mosquitoes |

2.2. Process of constructed wetland system

There are many kinds of artificial wetland processes. Currently, there are four types of push flow type, step flow water type, reflux type and comprehensive type [4-5], as shown in Figure 1.

Push flow is the most basic form. The stepped water inlet can avoid the blockage of the front part of the wetland bed, make the plant grow evenly, and is beneficial to the nitrification and denitrification in the back; the reflux type can dilute the influent water, increase the dissolved oxygen in the water and reduce the odor; It can also promote nitrification and denitrification in wetland beds, using low-lift pumps to perform oxygenation by means of water jets or water drops; on the other hand, water body
reflux is set on the one hand, and influent water is distributed to wetland beds on the other hand. The middle part to relieve the load on the front end of the wetland bed.

The operation of constructed wetlands can be combined in various ways according to the size of the treatment. Generally, there are single type, series type, parallel type and comprehensive type [6]. In practical applications, constructed wetlands are often combined in series with oxidation ponds and the like. In general, the system consists mainly of three parts [7]: (1) collection and pre-processing facilities. It consists of a wastewater water collection pipe network, a wastewater collection basin, a grid and a sedimentation tank. If water is taken from a polluted river, the wastewater collection network and wastewater collection basin can be eliminated. (2) Water distribution and water collection facilities. It consists of a water distribution well, a water distribution tank, a water distribution network, a water distribution pipe, a water collection pipe and a sump. (3) Wetland bed. According to the effluent water quality requirements, one or more stages of wetland beds can be designed, and the wastewater is purified several times through the wet bed in series or in parallel.

2.3. Mechanism of wastewater purification in constructed wetlands

Constructed wetlands use a combination of medium, plant and microorganism to purify wastewater, mainly denitrification and phosphorus removal. Denitrification: The denitrification of constructed wetlands is mainly through the adsorption and filtration of the medium, the absorption and adsorption of plants, the nitrification and denitrification of microorganisms. Nitrogen in wastewater is mainly divided into organic nitrogen and inorganic nitrogen. Microorganisms can remove organic nitrogen by nitrification and denitrification. The adsorption and filtration of medium and the absorption and adsorption of plants can remove inorganic nitrogen from water. Phosphorus removal: The constructed wetland mainly removes phosphorus from the wastewater by chemical precipitation, absorption of algae, and decomposition of phosphorus bacteria. When the wastewater flows through the constructed wetland, the organic phosphorus in the water is decomposed and transformed by the phosphorus bacteria, and the inorganic phosphorus is absorbed by the algae. More often, it reacts with iron, aluminum, and calcium oxides in the medium to form insoluble substances such as iron phosphate, aluminum phosphate, and calcium phosphate, which are finally removed by precipitation.

| Tab. 2 Comparison of nitrogen and phosphorus removal ability of plants |
|--------------------------|--------------------------|
| Nitrogen removal          | Water hyacinth > Lotus flower > Qi Yeping > Ziping |
|                          | Eichhornia crassipes > Duckweed > Floating |
| Dephosphorization         | Eichhornia crassipes (the strongest) |
|                          | Duckweed (the strongest) |

3. Design of constructed wetland wastewater treatment system

3.1. Construction of constructed wetland matrix

The substrate is the carrier of plant growth and is the reservoir of all living organisms and abiotics in the wetland, which connects the various processes occurring inside the wetland into a whole. It filters, precipitates and adsorbs pollutants during the wastewater purification process. In the design of constructed wetlands, the construction of the matrix needs to be considered in terms of the type, size and thickness of the matrix.

The artificial wetlands of different substrates have different purification effects. For wastewater characterized by P, it is best to choose fly ash and shale as the matrix, followed by bauxite, limestone and bentonite. The adsorption capacity of zeolite and oil shale for P is poor and should not be used. For wastewater characterized by organic pollutants and suspended solids, one or more of soil, fine sand and gravel are often used as a substrate to achieve a good treatment effect.

The size of the matrix particle size is the main factor affecting the hydraulic conductivity of the wetland system, which is directly related to the residence time of the pollutant in the wetland and the porosity of the system. The matrix with large particle size has large void content, and the amount of wastewater that can be accommodated is also large. The wastewater can be adsorbed and absorbed in
the wetland for a long time, which is beneficial to wastewater purification. The particle size of various substrates and their hydraulic conductivity are shown in the table below. At present, the constructed wetland has a matrix particle size ranging from 0 to 30 mm, and the most commonly used particle size range is 4 to 16 mm. Practice has shown that a matrix with a particle size of 8 to 16 mm has good hydraulic conductivity and is suitable for plant growth. The treatment effect is good [6]. However, for the matrix of the influent water distribution zone and the effluent catchment zone of the constructed wetland, gravel having a particle diameter of 60 to 100 mm is generally used.

The thickness of the substrate is an important parameter determining the cross-sectional area of the constructed wetland and the effect of wastewater treatment. It is generally determined according to the type of plant to be planted and the depth of growth of the root system to ensure the necessary aerobic conditions in the wetland bed. At present, the constructed wetland has a substrate thickness of 0.5-1.0 m, and most constructed wetland substrates have a thickness of 0.6-0.8 m. Generally, the matrix layer of the vertical flow wetland is relatively thick, between 70 and 80 cm, and the substrate thickness of the subsurface wetland is about 60 cm. The surface wettability requires less stringent thickness.

3.2. Constructed wetland structure and engineering parameters

The construction and engineering parameters of constructed wetland are the core of artificial wetland process design, including: hydraulic characteristics, wetland bed configuration and construction of supporting facilities: hydraulic characteristics include: hydraulic retention time, hydraulic load; wetland bed configuration design Including: hydraulic gradient, aspect ratio of wetland bed and water level control; the construction of supporting facilities includes: inlet and outlet devices, baffle devices and anti-seepage facilities.

$$t = \frac{V \varepsilon}{Q_{av}}$$ (1)

Where $t$ is the hydraulic retention time (d), $V$ is the wetland statistics (m$^3$), $\varepsilon$ is the wetland porosity (dimensionless), and $Q_{av}$ is the average flow rate (m$^3$/d).

The actual hydraulic retention time in the design is 40% to 80% of the theoretical value. Hydraulic slope: 0.5% or less for surface flow constructed wetlands; 0.5 to 2% for subsurface flow constructed wetlands. The BOD loading rate of the surface wetland inflow area is 100kg/(hm$^2$·d); the BOD loading rate of the subsurface wetland design is 80~120 kg/(hm$^2$·d).

$$A_s = \frac{QC_0}{ALR}$$ (2)

Where $A_s$ is the wetland treatment area (hm$^2$), $Q$ is the wetland influent flow rate (m$^3$/d), and $C_0$ is the mass concentration of the influent pollutant (kg/m$^3$).

Wetland bed length:

$$L = A_s / W$$ (3)

Width of the undercurrent wetland:

$$W = \frac{1}{2} \frac{QA_s}{Kdh \cdot DW}$$ (4)

The length of the wetland bed is usually 20 to 50 m. If it is too short, the effective treatment area is too small to ensure the purification effect; if the wetland is too long, it will easily cause a dead zone, making the water level difficult to adjust, which is not conducive to plant growth. The aspect ratio of the system should be 2:1. The depth of the surface wetland is 10 to 200 cm, the water depth of the plant is 60 cm, and the depth of the submerged plant is about 120 cm.
3.3. Typical Process - Corridor Constructed Wetland System
In view of the characteristics of rural wastewater dispersion and small processing scale, Zhang Keqiang and others used a uniquely designed corridor-type constructed wetland to treat it. The wetland system combines the subsurface flow with the surface flow. The treatment units at each level are stepped, with the corridor curve as the bypass path, and the corresponding aquatic plants, which can effectively reduce the wetland area and solve the winter operation problem. The scale of rural wastewater dispersion treatment and reuse.

The wetland system consists of a three-stage processing unit, as shown in Figure 2. The first stage is in the innermost circle of the system, is a circular structure, adopts vertical subsurface flow technology, and is equipped with appropriate matrix, plant and intermittent water inlet to help the system microbial aerobic respiration and nitrification, for BOD5, COD The degradation effect of SS is better. The other levels of the wetland are designed with a circular ring structure concentric with the first stage. The second stage uses a horizontal submerged flow process, which is one of the main processing units. The anaerobic treatment capacity and organic matter degradation ability are strong, and most of them can be removed. BOD5, COD, SS and some nitrogen and phosphorus. The third stage can be selected according to the winter temperature, and the subsurface flow process can be adopted in the cold area. The surface area flow process can be adopted in the warm area, supplemented by the different substrates and plants from the first two stages, and the secondary effluent is further treated by biological action. Thereby removing nitrogen and phosphorus more effectively and thoroughly. As shown in Fig. 2, the corridor type sewage treatment system is cited in the paper "DEMONSTRATION OF WATER LOOPS WITH INNOVATIVE REGENERATIVE BUSINESS MODELS FOR THE MEDITERRANEAN REGION".

4. Improved analysis of constructed wetland wastewater treatment

4.1. Choosing the right medium
The medium has great significance in the constructed wetland wastewater treatment system. The choice of medium will affect the treatment effect of wastewater, the growth of aquatic plants and the reproduction of microorganisms. At present, there are many media widely used, such as soil filler, pebble filler, ceramic filler, etc. Each medium has its advantages and disadvantages, but all media should meet the following requirements: 1) The texture of the medium should be light and loose. Small degree, sufficient mechanical strength can carry the growth of plants; 2) large surface area, more pores, which is conducive to the adhesion of microorganisms, improve the hydraulic performance of wetlands; 3) the medium is non-polluting, does not emit harmful substances, and has good chemical properties; 4) The degree of loss in water is small, the shape factor is high, and it has strong adsorption capacity. It will not
be denatured for long-term use; 5) The filtration effect is good, the water quality after purification is good, and the oxide content of iron, aluminum and calcium in the medium high.

4.2. Choosing the right plant

Plants have a certain ornamental effect, can purify the air, and also have the effect of odor control to improve the wastewater treatment effect, and also create an environment for microbial growth. For the constructed wetland wastewater treatment system, it is important to select suitable plants. The rush can remove pathogens and remove chemicals such as chlorinated hydrocarbons and phenols from the water; the cattail leaves can absorb heavy metal elements, chlorinated hydrocarbons, etc. in the water, while the roots can secrete natural antibiotics, effectively removing bacteria from the water; Grass is mainly used to catch insects such as mosquitoes and flies; every 100g of water onion can purify 200mg of phenol in 100 hours, and BOD in water can be reduced by 60%~90% in 14 days; 8mg of phenol can be decomposed per 100g of reed one day. In the construction of constructed wetlands, suitable plants should be selected according to different needs to improve the performance of the wastewater treatment system.

4.3. Choosing the right wetland bed construction

There are two forms of wetland bed construction in a constructed wetland wastewater treatment system: a horizontal flow system, a vertical flow system. The horizontal flow system is easy to remove SS and bacteria, and can remove BODs at a certain dissolved oxygen level, which is convenient for microbial denitrification. However, due to the poor oxygen delivery capacity of the system, it is not conducive to microbial nitrification; vertical flow system due to oxygen delivery capacity Good, it is good for microbial nitrification, can remove BODs and COD well, can remove bacteria in water, but it is easy to block and the treatment effect is not good. At first, people used horizontal systems, mainly because of its low cost and low consumption. Later, vertical systems were widely used. When selecting a processing system, the two should be combined to complement each other. The vertical flow system can be placed in front of the system to facilitate oxygen delivery. The horizontal processing system can be placed in front of the vertical system to remove the TSS and prevent blockage. At the time of design, pay attention to the combination of the two processing systems to create the most efficient processing system construction.

5. Conclusion

Constructed wetland systems have economic, environmental and social benefits. The effluent treated by constructed wetland has good water quality and can be reused in agriculture, forestry, animal husbandry, deputy, fishery, and can also be used in the entertainment industry. Wetland plants can also be recycled, such as using it to produce biogas, producing feed, etc. It is transformed from abandoned ravine land and low-lying land. While rationally developing and utilizing land, it adds green to the environment and increases habitat for wild animals, thereby increasing the value of the regional landscape and bringing people a beautiful enjoyment; Constructed wetlands can also serve as a base for environmental education and publicity, helping to change people's ecological concepts, promoting the concept of saving water resources and reusing renewable resources, and enabling people to build a new life concept that respects nature.

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