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Research on Construction Technology for Water Quality Improvement Using Herbaceous Plant Biofilm in Small Watershed Rivers

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***Abstract*— Small watershed rivers, due to their limited pollution capacity and weak self-purification function, are easily affected by domestic sewage and agricultural non-point source pollution, leading to water body blackening and ecological degradation. Traditional treatment technologies rely on interception and chemical treatment, which come with high costs and significant risks of ecological damage. This study proposes a water quality improvement technology based on the concept of ecological restoration, integrating biological film aeration, microbial enhancement, and the synergistic effect of aquatic plants. Through practical river engineering projects in Nan 'an City (such as Pengmei Creek and Liankeng Creek), this technology has been verified to significantly increase dissolved oxygen (DO ⩾ 2 mg/L), reduce pollutants (COD removal rate ⩾ 75%, ammonia nitrogen removal rate ⩾ 80%), and restore the water body's self-purification ability. The research results provide an economically efficient and environmentally friendly solution for small watershed river management, with significant theoretical and practical value.**

***Index Terms*— small watershed river; biofilm technology; phytoremediation; microbial enhancement; ecological treatment**

I. INTRODUCTION

Small watershed rivers serve as vital ecological corridors between cities and rural areas, undertaking flood control, drainage, water source conservation, and landscape functions. However, with the acceleration of urbanization, large amounts of domestic sewage, agricultural non-point source pollution, and industrial wastewater are being discharged into these rivers, leading to frequent issues such as eutrophication, insufficient dissolved oxygen, and black and odorous bottom sediments[1]. Taking a city as an example, monitoring data from 2023 shows that about 35% of the small watershed rivers in the city do not meet Class V water quality standards, with ammonia nitrogen and chemical oxygen demand (COD) exceeding limits at rates of 42% and 28%, respectively[2]. Traditional treatment methods, such as intercepting sewage and chemical coagulation, can improve water quality in the short term but come with high engineering investment, high operating costs, and risks of ecological damage, making them unsuitable for sustainable development needs. In light of this, environmentally friendly ecological restoration technologies have become a current research hotspot.

In order to continuously improve the living environment, fight the battle of pollution prevention and control, practice the concept that "green mountains and clear waters are gold and silver mountains", and achieve the goal of ecological restoration of small river basins, a comprehensive water quality improvement technology system has been formed and applied in various types of river management.

II. PROJECT OVERVIEW

2.1 Project objectives

In a certain urban area, the A Stream river project spans only a few hundred meters. The water in this section appears in three colors, forming stagnant zones where dissolved oxygen levels are low. Anaerobic fermentation of the sediment causes it to float, and the water quality at cross-sections has long been below Class V standards. This affects the achievement of the environmental protection target responsibility document issued by the municipal party committee and government, which stipulates that "the proportion of sections in the main basin meeting Class III water quality standards should be 100%, with no sections below Class IV or V standards." To accelerate the improvement of river water quality, plans are underway to enhance the water quality from the overflow dam to the assessment cross-section over a 100m stretch using engineering measures, aiming to bring it up to Class V surface water standards.

2.2 Technical route

According to the current water quality assessment and cause analysis, due to the river being relatively narrow (<20m), the flow rate is slowed by the upstream support from the downstream section, making it difficult to achieve compliance through direct water transfer or on-site treatment. After comparing multiple options, it was ultimately decided to construct an overflow dam at the mouth of Stream A to prevent the formation of a dead water zone downstream; simultaneously, pumping will be used to draw the river water in front of the dam to the wastewater treatment facilities set up along the shore, and the treated water will then be discharged behind the dam, as shown in Figure 1.

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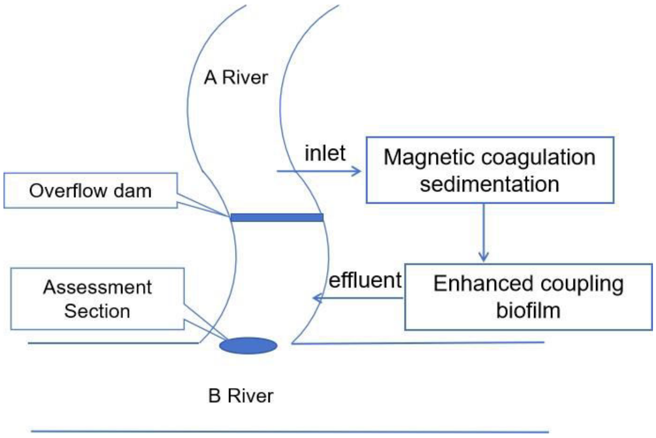

Fig.1 Overall governance idea plan diagram

2.3 Design water quality and quantity

According to the water quality monitoring data of River A in 2023, the highest COD was 93 mg/L, with an average of 33 mg/L; the highest ammonia nitrogen was 15.5 mg/L, with an average of 4.69 mg/L; and the highest TP was 1.47 mg/L, with an average of 0.54 mg/L. The pollutant content peaked in December 2017, when COD exceeded standards by 1.33 times, ammonia nitrogen by 6.75 times, and TP by 2.68 times. Except for a few months that were classified as Class V, all other months were classified as sub-Class V. Based on the current water quality and project objectives, the design influent and effluent water qualities are shown in Table 1.

Table 1 Design water inflow and outflow quality

project	COD (mg/L)	BOD5(mg/L)	ammonia nitrogen (mg/L)	TP(mg/L)	pH price
Design inlet water quality	100	40	8	1	6~9
Design water quality	40	2	6	0.4	6~9

III. EHBR ENHANCED COUPLING BIOFILM TECHNOLOGY

3.1 Current situation of ecological restoration technology application

Ecosystem restoration refers to the use of an ecosystem's self-recovery capabilities, supplemented by artificial measures, to gradually restore damaged ecosystems or guide them towards a virtuous cycle, reducing and controlling environmental pollution while enhancing visual and aesthetic enjoyment. For example, biofilm technology achieves efficient pollutant degradation through microbial attachment and growth; phytoremediation utilizes aquatic plants to absorb nitrogen and phosphorus and accumulate heavy metals; microbial enhancement techniques accelerate organic matter decomposition by adding highly effective bacterial agents. However, single technologies have limitations: biofilms are susceptible to hydraulic conditions, phytoremediation has a long cycle, and microbial agents lack sufficient stability [4]. How to improve governance efficiency through the coupling of multiple technologies is now a key focus of research.

After investigation, the main pollutants in Guangzhou Metro Line A are COD, ammonia nitrogen, and TP. The influent COD is <100 mg/L, with dissolved and non-dissolved COD each accounting for about 50%. Non-dissolved COD can be treated using coagulation sedimentation, which involves adding coagulants and flocculants to form flocs, followed by separation through sedimentation tanks; the concentration of dissolved COD is not high and can be removed using aerobic biological treatment. Considering the need to remove ammonia nitrogen and TP, it is proposed to use EHBR enhanced coupled biofilm technology.

3.2 EHBR enhanced coupling biofilm technology process principle

EHBR enhanced coupled biofilm technology is a new type of wastewater treatment technology suitable for water body management projects with flow rates less than 4 m/s, such as water purification and river remediation. This technology rapidly increases dissolved oxygen and microbial proliferation in rivers through the coupling of biofilm and aeration techniques, providing an excellent environment for plant growth within the river. High-efficiency strains are selected and cultivated to form microbial composite agents for treating polluted water bodies. The process is based on enzymatic reactions, using special proteins with catalytic functions produced within the organisms as catalysts to purify wastewater, decompose sludge, and eliminate odors [5].

A nano-aeration biofilm reactor is used, which is filled with packing material, allowing the biofilm to grow on its surface. The upper part of the reactor is connected to the aeration machine's inlet pipe, while the lower part is connected to the aeration machine's outlet pipe, ensuring that bubbles mix uniformly with the wastewater and pump it into the reactor for aeration. The effluent from the reactor is connected to the discharge pool via an electromagnetic valve.

Microorganisms attach and grow on the outer surface of fibers, forming a multifunctional biofilm. The surface area of the biofilm in the reactor can reach 1000-2000 m^2/m^3 (reactor). The microbial film attached to the outer side of the fibers comes into full contact with wastewater, where organic matter and ammonia nitrogen are adsorbed and decomposed by the biofilm, thus purifying the wastewater.

Fig.2 Coupled biofilm

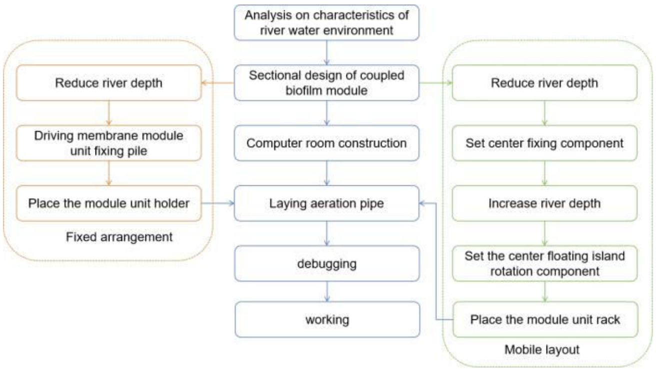

Fig.3 Construction process flow chart

3.3 Key points of operation

3.3.1 Layout method

The implementation of EHBR enhanced coupling biofilm technology requires that the use conditions of the technology be met, that is, to maintain the water depth of the river at least 0.5m above. In order to ensure the required water depth, it can be set by two types of layout, namely fixed and mobile.

(1) Fixed layout

Reduce river water depth: Lower the aquatic level in the river to around 0.5~0.8m, ensuring personnel can accurately locate the biofilm. Weld the membrane module frames on the bank in advance and check that the frames are securely fixed. Use galvanized steel pipes for this purpose, inserting them 1.5m into the riverbed and raising them 0.5m above it, binding them to the membrane module units. Along the cross-section of the river, set one frame every 3m. Connect the welded membrane module frames to the galvanized steel pipes. During operation, the membrane resembles aquatic plants floating at the bottom of the water.

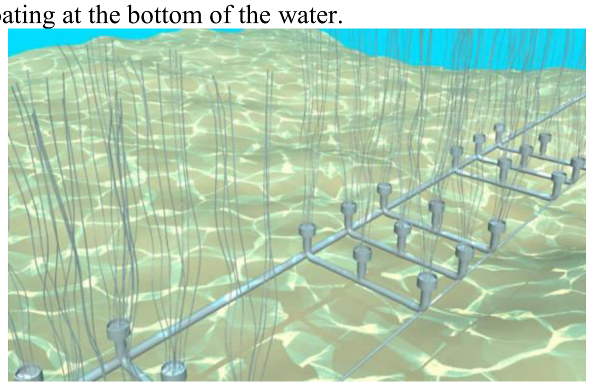

Fig.4 Three-dimensional diagram of fixed membrane body

(2) Mobile layout

Reduce river water depth: Lower the river water depth to around 0.5~0.8m to ensure personnel can accurately locate the biofilm. Drive an axis component into the center of the river and set triangular supports around it. The axis component is fixed with flexible steel connections to the floating island, allowing the island to rotate under the influence of the current. The biofilm is suspended from the floating island. By using membrane flotation, the contact area between the biofilm and the water body is increased. Under the rotation of the floating island, turbulence is generated in the water, further enhancing the purification capacity of the biofilm.

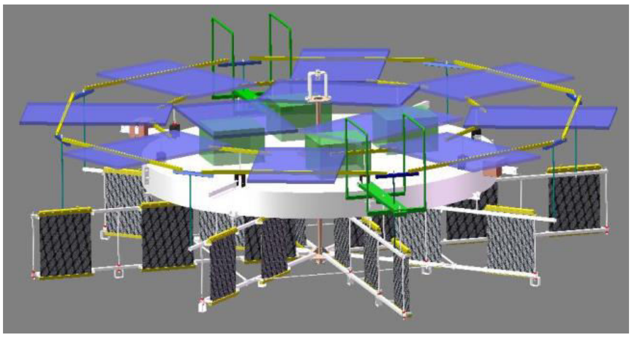

Fig.5 Schematic diagram of mobile membrane system

3.3.2 Construction of aeration room

Each server room can accommodate 3 to 5 aeration oxygenators, model TC-N-3.7, with an oxygen supply of 3.6~5.3kg/h. The server room is part of the biofilm system and is placed on the shore. The suction pipe and drainage pipe connect to the membrane system. During operation, the suction pipe draws water from the river into the system, where microbubbles are mixed in, then discharged through the micropores of the membrane components back into the river, mixing with the river water. This process increases dissolved oxygen levels in the river and enhances the activity of indigenous microorganisms.

3.3.3 Laying aeration pipe

The main aeration pipe uses UPVC pipes, primarily connecting the aeration room and membrane components. It is fixed to the shore slope with U-shaped steel forks, ensuring the main aeration pipe is securely in place. The branch aeration pipes are installed side by side in strips, with an installation spacing of 5~10m per line. During installation, steel ropes are used to bind the pipe body and the bottom biological film support, then tie the biological film to the branch aeration pipes together. All horizontal heights should be as consistent as possible to facilitate gas distribution balance.

3.3.4 Commissioning

(1) Test operation of the machine room

Before starting the aerator, the operator must check for any abnormalities in all parts of the equipment under power-off conditions. Since the aerator operates continuously with high power and load, it is essential to frequently inspect the lubrication of the reducer and coupling. Check if the water immersion depth of the aerator disc meets the process requirements. Switch the transfer switch to manual position, press the operation button to start the aerator, and observe the equipment's operation for any noise or abnormalities. If any abnormalities occur, immediately press the red stop button to cut off the power supply and report to the production operations department. The operations department will organize personnel to investigate the situation and resolve the fault. After manually operating the aerator normally, it can be put into automatic operation mode. The operator should monitor the machine for ten minutes to observe its performance, and subsequently conduct regular inspections of the equipment.

(2) Selection and breeding of microbial strains

The main advantage of microbial preparation technology is its ability to rapidly increase the concentration of microorganisms in polluted media and is expected to enhance the biodegradation rate of pollutants in a short period. Additionally, biological reactions typically occur under mild conditions, with low investment, minimal costs, and low consumption. The process is effective, stable, and easy to operate. However, to maintain good water quality improvement effects, continuous addition based on changes in the water body is required, making it an auxiliary measure in the ecological restoration of water bodies. This technology is suitable for use in enclosed slow-moving water bodies before large-scale algal blooms, addressing the common issue of longer effectiveness times associated with microbial preparations[6].

(3) Sowing microbial strains
Microbial inoculation is mainly carried out by artificial river surface sowing. By selecting composite microbial agents such as "bacillus, photosynthetic bacteria, nitrifying bacteria, lactic acid bacteria, and oxygenating bacteria," and combining the microbial concentration, temperature, aeration volume, aeration method, and water flow rate to determine the frequency of microbial inoculation.

3.3.5 Herbaceous aquatic plant cultivation
Aquatic plant technology is a vital component of river ecosystems, with significant environmental and ecological functions. By using aquatic organisms to cultivate plants, the growth of these plants helps transfer pollution loads from the water system. Their well-developed root systems provide a habitat for microorganisms to decompose pollutants in the water, which can then be absorbed by the plants. This process has certain capabilities in absorbing and purifying water, clarifying water quality, and inhibiting algae growth[7].

ANALYSIS OF IMPLEMENTATION EFFECT

The project was implemented in February 2024, and the water quality was monitored at the effluent outlet of EHBR purification pond. The continuous measured water quality from June 13 to 19 is shown in Figure 5.

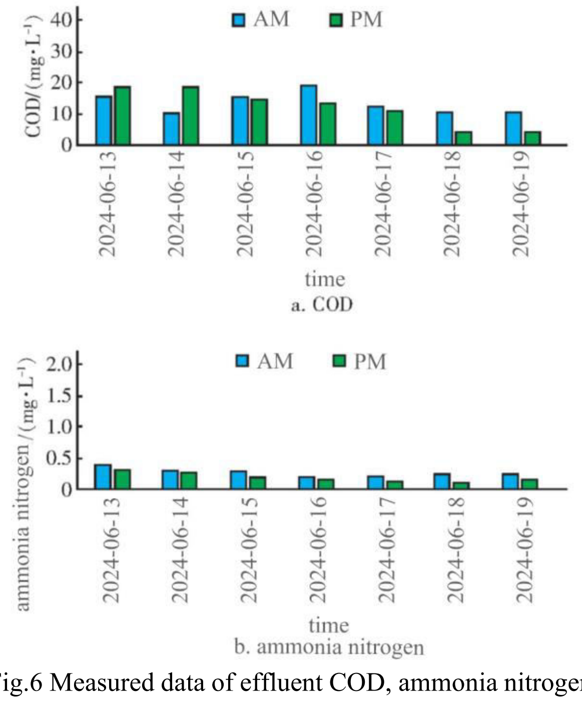

Fig.6 Measured data of effluent COD, ammonia nitrogen and TP

The EHBR system installed in the pond underwent nearly two months of microbial biofilm formation and acclimatization, resulting in a mature EHBR biofilm. Under the pretreatment conditions of magnetic coagulation sedimentation, the deep purification by the EHBR system significantly reduced the COD, ammonia nitrogen, and phosphorus content in the water. The actual operational performance far exceeded expectations, meeting Class IV surface water standards, demonstrating the excellent water purification capabilities of the MagCS + EHBR coupled system. After the water from the EHBR purification pond flows into the river, the water quality at downstream monitoring sections reaches Class V standards, achieving the design objectives of the project. Additionally, due to the improvement in water quality, the ecosystem of the pond has gradually recovered, with the appearance of numerous fish, shellfish, and other aquatic animals, as well as the growth of extensive aquatic plants, making the water body clear and highly transparent.

IV. CONCLUSION

This study integrates biofilm aeration, microbial enhancement, and phytoremediation technologies to construct an efficient water quality improvement system for small watershed rivers. Engineering practice has shown that this technology can rapidly restore dissolved oxygen in the water body, significantly degrade pollutants, and offer notable economic and social benefits. Future efforts should focus on further optimizing technical details to promote its large-scale application in broader regions.

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