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Concluding Remarks

Thi Thuong NGUYEN

Through rapid development with inadequate water treatment facilities, a dilemma frequently found in developing countries, substantial volumes of wastewater laden with various pollutants are being discharged into water sources, resulting in adverse health and environmental consequences. Conventional wastewater treatment processes face limitations due to their high energy requirement, elevated costs, and limited feasibility for widespread adoption in rural areas. Consequently, ecological technologies are garnering increased attention as alternative solutions for wastewater treatment. constructed wetlands (CWs) have emerged as prominent and optimal methods within ecological technologies for sustainable, cost-effective, and environmentally friendly waste treatment solutions. However, achieving sustained removal performance and meeting acceptable wastewater standards necessitates the development of appropriate strategies and techniques.

The content of this volume is a record from the international workshop named "New Challenges in Constructed Wetlands for Sustainable Wastewater Treatment: Intensification Strategies Based on Asian Experiences" that was held in July 2023, hosted by the Asia-Japan Research Institute (AJI), Ritsumeikan University. We express our sincere gratitude to all the presenters who contributed to this volume, for generously sharing their knowledge and experience in utilizing CWs for wastewater treatment, as well as strategies for enhancing the treatment performance of CWs in specific operating conditions and areas.

Following each presentation, we conducted Q & A sessions, followed by a final discussion session. Our discussions focused on the following main issues discussed below.

1. CWs as an Affordable and Sustainable Wastewater Treatment Method

CWs offer a cost-effective and eco-friendly approach to wastewater treatment, showcasing numerous advantages over conventional treatment plants. This was underscored by all eight researchers in their respective presentations during the workshop. Throughout the event, the potential of CWs to address diverse wastewater types — including aquaculture wastewater, hospital wastewater, domestic wastewater, mine drainage, swine wastewater, greywater, landfill leachate, RO concentrate, and urban stormwater runoff — was thoroughly explored and discussed.

Their low construction and operation costs make them an appealing option, as they utilize simple materials like gravel, sand, and native plants, which are both readily available and inexpensive. This affordability makes them accessible for various applications, from individual households to larger communities or industrial settings.

One of the key benefits of CWs is their reliance on natural treatment processes. By harnessing filtration, adsorption, and microbial degradation, they efficiently remove pollutants from wastewater. Plants and microorganisms within the wetland ecosystem play crucial roles in breaking down organic matter, removing nutrients like nitrogen and phosphorus, and trapping sediment and contaminants. This natural approach not only enhances water quality but also minimizes the need for mechanical aeration and energy inputs, making CWs highly energy efficient. Moreover, CWs contribute to biodiversity conservation and habitat creation. By creating diverse ecosystems, they support a variety of plant and animal species, including birds, insects, and aquatic organisms. This biodiversity not only enriches local ecosystems but also provides ecological benefits such as habitat restoration and wildlife preservation.

The scalability and flexibility of wetland systems further add to their appeal. They can be designed and constructed to accommodate various scales of wastewater treatment, making them suitable for a range of applications. Additionally, their adaptability to different site conditions allows them to be integrated into existing landscapes seamlessly. Treated effluent from CWs is often of high quality and suitable for non-potable reuse, such as irrigation, groundwater recharge, or recreational purposes. This water reuse not only conserves valuable freshwater resources but also improves overall water quality by removing pollutants and enhancing aesthetic characteristics.

CWs also offer resilience to climate change impacts. By acting as buffers against flooding and storm surges, they mitigate the risk of water pollution and provide valuable ecosystem services in the face of increasing precipitation and extreme weather events. Furthermore, these systems provide opportunities for community engagement and education. By serving as educational resources and recreational amenities, they foster a sense of stewardship and environmental awareness among local communities. This engagement helps raise awareness about the importance of wetlands in water management and ecosystem health, empowering communities to take proactive steps towards conservation and sustainability.

2. Techniques and Strategies for Enhancing Performance in CWs

While CWs offer numerous benefits over conventional technologies, their effectiveness can vary significantly depending on the nature and design of the CW system. Achieving sustainable removal performance and meeting stringent effluent requirements, especially when treating wastewater with complex pollution characteristics and variable pollutant loadings under extreme conditions, necessitates the development of more suitable strategies and techniques. This was the primary focus of discussion at the workshop. Eight Asian researchers presented methods aimed at enhancing the treatment efficiency of CWs tailored to the specific conditions of each region.

Dr. Dan A implemented a tidal flow operation strategy featuring an intermittent mode: one day with wastewater (wet phase) followed by a day without wastewater (dry phase). This approach aims to enhance aerobic conditions in CWs for antibiotic removal because oxygen plays a critical role in controlling nitrification and the biodegradation of organics.

To address urban wastewater treatment challenges in densely populated cities with limited land availability, such as Ho Chi Minh City, Vietnam, Dr. Thi Dieu Hien Vo proposed installing shallow-bed CW systems on the rooftops of buildings for wastewater treatment. She utilized shallow-bed CW systems integrated with rock, charcoal, and oyster shells as substrates to enhance the removal of nitrogen and phosphorus from domestic wastewater. Additionally, she integrated ornamental flowering plants, specifically Campsis radicans and Vernonia elliptica, into the CW system to further improve wastewater purification and create an aesthetically pleasing landscape.

Coming from South Asian countries such as India, Bangladesh, and Sri Lanka, which are facing significant challenges related to rapid population growth, climate change, water pollution, and water shortages, South Asian researchers have proposed CWs as suitable solutions to treat wastewater. To enhance wastewater treatment and reduce land requirements, Dr. Saurabh Singh from India used an algorithm to predict k-values, the first-order areal rate coefficients, to optimize the design of Horizontal Flow Constructed Wetlands (HFCWs) in terms of area requirement for organics and nitrogen removal from wastewater. He found that the use of deep HFCWs provides a conducive environment for in situ growth and the coexistence of diverse microbial populations supporting contaminant and nitrogen removal, specifically anammox bacteria. Dr. Nehreen Majed from Bangladesh introduced her endeavors to improve wastewater treatment, such as using hybrid CW systems and electrodes-integrated CWs for landfill leachate treatment. Notably, the electrodes-integrated CWs showed excellent treatment performance attributed to providing additional surface area for microbial attachment and electron transfer, thereby promoting the degradation of organic matter and the removal of pollutants from wastewater. Additionally, microbial fuel cells (MFCs) harness the microbial metabolism of organic matter to produce electricity, which can potentially be harvested for various applications, thereby offsetting energy costs associated with wastewater treatment. Besides these, planted electrodes offer a stable and durable substrate for microbial attachment and biofilm formation, ensuring the longevity of the microbial community within the MFCs, leading to consistent and reliable performance over time. From Sri Lanka, Dr. Shiromi Dissanayaka incorporated native plants, namely Thunhiriya, and fungal inoculum into CWs to enhance greywater treatment. Fungi, particularly mycorrhizal fungi, can absorb and assimilate nutrients such as nitrogen and phosphorus from wastewater. Introducing fungal inoculum can enhance the nutrient removal efficiency of CWs, thus improving water quality. Additionally, fungi form symbiotic relationships with plant roots, promoting wetland plant growth and health. She also investigated the use of native materials such as Grumusol in Sri Lanka and recycled materials (clay brick, laterite brick) as substrates in CWs to enhance nutrient and metal removal, respectively.

Dr. Thi Thuong Nguyen inoculated microorganisms into the CW system by adding pond sediment. In addition, an external carbon source from domestic wastewater was also added to the wastewater to promote the biological processes for heavy metal removal from acid mine wastewater in Japan. The results showed that CW treatment performance increased by around 20% compared to the period without external carbon source supplementation.

Another strategy for improving wastewater treatment involves utilizing materials with high adsorption capacity. Dr. Obey utilized corncobs, an agricultural byproduct, to produce biochar, which was then examined as a filter material in CWs to enhance wastewater treatment. Corncob biochar, with its high surface area, porous structure, and cation exchange capacity, proves effective in adsorbing contaminants and providing a habitat for beneficial microorganisms. These microorganisms aid in organic matter degradation and contaminant transformation, thereby boosting pollutant removal efficiency. Additionally, corncob biochar buffers pH fluctuations, maintaining an optimal environment for microbial activity and nutrient uptake by plants. Furthermore, its resistance to decomposition improves the longevity and stability of CWs, ensuring sustained treatment performance over time. Dr. Obey's research revealed that corncob biochar exhibits a high capacity to adsorb antibiotics (CFX, OFX, and DLX). A pilot-scale CW filled with corncob biochar was conducted for treating swine wastewater, demonstrating effective removal of organic matter and nutrients, and meeting effluent quality standards for discharge into surface waters.

Similarly, focusing on the substrate, one of the three main components of CWs, Dr. Van Tai Tang developed advanced porous concrete combined with filler materials such as zeolite, slag, and activated carbon to enhance the treatment performance of CWs for urban stormwater runoff. Additionally, durability, high water infiltration, and support for plant growth are also advantages of advanced porous concrete in stormwater decontamination and management, as well as in creating urban landscapes.

3. CWs Challenges and Future Perspectives

In recent years, there has been a significant and rapidly growing interest in utilizing new strategies and techniques to improve removal efficiency in CWs. Pollutant removal in CWs involves a complex interplay of physical, chemical, and biological processes, which can be greatly affected by various environmental and operational factors. However, the primary mechanisms and pathways responsible for removing pollutants remain unclear. Further studies are required to elucidate these mechanisms and pathways, particularly focusing on understanding the structure and distribution of microbial communities. Identifying associated bacteria that aid in the removal process will also be crucial for optimizing the treatment performance of CW systems. Additionally, it is essential to assess the influence of operational factors and optimize design parameters to encourage the development of new removal pathways within the system.

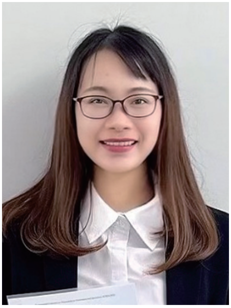
Another significant challenge of CWs is assessing their long-term performance. Existing studies primarily focus on small-scale and short-term assessments, which makes it difficult to comprehensively evaluate the effectiveness of CWs over extended periods, such as 10 or 20 years. To advance CW technology, there is a need for more research on large-scale CWs treating real wastewater. Furthermore, studies should prioritize the evaluation of long-term performance.

Using industrial materials like fly ash, steel slag, or mortar in CWs showed promise for enhancing pollutant removal. These materials often boast ample surface areas, providing ideal habitats for microbial communities crucial in breaking down pollutants such as heavy metals or organic contaminants. Furthermore, repurposing industrial waste as substrates offers an eco-friendly solution for waste disposal, alleviating pressure on landfills and curbing environmental pollution. However, potential adverse effects warrant attention. Some industrial materials may leach harmful substances into water, jeopardizing water quality and aquatic life. Additionally, evaluating the long-term stability and durability of these materials in wetland settings is imperative. Substrate degradation or structural failure could lead to pollutant release or disrupt wetland functions. Thus, thorough risk assessment and monitoring are vital to mitigate adverse effects and optimize artificial wetland systems' efficacy.

Additionally, to ensure the sustainability of CWs in wastewater treatment, it is essential to incorporate economic, social, and environmental protection aspects. While technical strategies have been successfully developed to improve treatment efficacy in CWs, the assessment of CW sustainability has been overlooked. Hence, there is a necessity for comparative analysis and evaluation of these CWs to better comprehend environmental and social sustainability. Moreover, specific cost-benefit analyses for these applications are largely absent. Therefore, further research should focus on investigating and evaluating this aspect in real-scale applications to enhance understanding of their full potential and accuracy.

The widespread implementation of CWs faces several challenges, including limited land availability, lack of awareness among policymakers and stakeholders, and inadequate funding. Moreover, climate change-induced alterations may affect CW performance. Thus, integrating CWs into urban planning and development strategies for sustainable water management, alongside supportive policies and regulations, is crucial. Promoting knowledge sharing and capacity building among stakeholders is essential to facilitate best practices and innovation in CW implementation and management. Incorporating CWs into climate change adaptation and mitigation strategies at national and regional levels, particularly in Asia, can help reduce coastal vulnerability and provide natural flood management infrastructure.

5. Dr. Thi Thuong NGUYEN



Chapter 5. Constructed Wetlands Planted with Iris for Mine Drainage Treatment: Effects of Domestic Wastewater Feeding on the Removal of Multiple Heavy Metals

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