Rethinking Intensification of Constructed Wetlands as a Green Eco-technology for Wastewater Treatment

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Constructed wetlands (CWs) comprise a suite of recognized eco-technologies that are designed and constructed to mimic and manipulate the simultaneous physical, chemical, and biological processes occurring in natural wetlands for wastewater treatment purposes. Besides the water quality improvement function, CWs also provide a multitude of other functions, such as biodiversity, habitat, climatic, hydrological, and public use functions. Since the 1960s, the annual number of publications in the Web of Science Core Collection in this field has increased exponentially to >350 in 2017 (Figure 1). The most attractive benefit of this technology is its "green" and ecofriendly way of treating wastewater, with low operational costs and easy maintenance. Because of these eco-characteristics and economic advantages, CWs have been well documented in guidelines as an alternative to conventional centralized wastewater treatment systems.

Along with the growing attention to CW technology paid by both scientists and engineers in the last five decades, knowledge gained from diverse fields of research has gradually turned understanding on CW from a "black box" model to a "grey box" model. However, the effort devoted to understanding the cycling of basic elements, such as carbon, phosphorus, nitrogen, and sulphur, and their complex interactions in these systems, seems to lag far behind the pace of engineering applications. This understanding is needed particularly where CWs are trialed for the treatment of various industrial effluents that have not been attempted before (1). In recent years however, several intensifying strategies involving new system configurations, sometimes even without plants, technical amendments, and operations with high external energy use, are emerging in literature. Currently, the number of publications reporting on various types of intensified CWs constitutes nearly a quarter of those published in this field (Figure 1). Although it is questionable to define many of the "intensified CWs", these new types of CWs are driving the CW technology away from its eco-characteristics and economic benefits. The CW intensification is responding to new challenges where CWs passive systems present limitations and cannot produce the demanded effluent quality. Some of the new intensifying techniques are, however, only tested under laboratory scale conditions and are not as yet applied in full-scale systems.

In our view, it is time to focus attention to this intensification strategy and urge a rethink on the future developments of CW technology. Should we intensify these systems using technical means to increase their pollutant removal performance and capacity, but risk losing their ancillary benefits? This in turn raises the question to rethink about how it would be wise to further intensify the performance of CW systems but maintain their ancillary functions.

(1) **Intensification reduces the footprint of CWs**

A main benefit of CW intensification lies in the improved treatment capacity and the concurrent lower footprint of the systems *(2)*. However, in low-populated rural areas and in many developing countries, land availability may not be such an issue. Even though the intensification of CWs can improve treatment efficiency, it would certainly increase the maintenance complexity and operational costs of the systems, which could be a challenge in some regions with limited financial resources. Some slightly intensified CWs, without too much process intensification and energy-demand, might be feasible. Besides, the strong seasonal nature of pollutant loading and the need to have a system with an established microbial community in a fixed bed may warrant such 'intensification'. However, the balance of its basic eco-characteristics, low operational costs, and easy maintenance, along with treatment capacity, must remain an important consideration.

(2) **Intensification widens the application of CWs**

The application of CWs has expanded quickly to treat various types of wastewater, which may contain a range of toxicants, including high concentrations of salt, high acid or alkaline compounds, and a diverse array of toxic chemical compounds. The long-term effects of these toxicants on wetland vegetation and associated microorganisms have not been well studied. But these toxic compounds may be the reason for the observed withering of plants and disruption of treatment performance in CWs handling different types of industrial wastewater. Even though intensification may accelerate the pollutant transformation processes by increasing the functional microbial activity, and concurrently relieve the potential negative impact from specific toxic contaminants, integration of other wastewater treatment technologies is recommended in the treatment train, which cannot be replaced by intensified CWs *(3)*.

(3) **Intensification may make wetland vegetation redundant**

Wetland vegetation is an indispensable component on CWs, since the plants provide many significant functions in relation to the treatment processes as well as ancillary functions, such as biodiversity and food chain support. However, intensification strategies, such as forced pressurized aeration may make the role of plants obviously become less or non-existent. Also, the forced aeration may impede the growth of the plants *(4)*. In such systems, from a treatment perspective, it might be an advantage not to have vegetation growing in the beds, as the systems can then be covered or even buried under the ground. The reason to maintain a vegetative cover in these intensified systems seems to be that the green image of the CW-technology can be used as a sales argument.

(4) **Intensification may reduce microbial community diversity**

Due to strict discharge limits for specific water quality parameters, intensification of CWs often results in the stimulation of microbial communities processing the targeted pollutants, e.g., organic matter or ammonium. The role of other microbial communities may be weakened or lost under this treatment intensification. These microbial communities may be important for degradation of emerging pollutants, such as pharmaceuticals and personal care products. High microbial diversity is a critical characteristic of an eco-treatment system, while this aspect may be undermined in intensified CWs.

Therefore, it is necessary to urge engineers and scientists to keep in mind one of the principles of ecological engineering in relation to constructed wetlands: “do not over-engineer the system, design it with nature, not against it” *(5)*. Considering pollutant nature, concentration, and seasonality, some intensifications are suitable; however, operation and maintenance issues and the natural character of CWs must be the priority.

Declaration

The authors declare no competing financial interest.

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