Chemical Engineering Journal 279 (2015) 220–230

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Review

A review of incorporation of constructed wetland with other treatment processes

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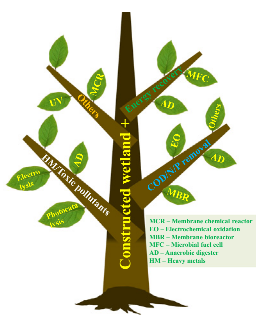
HIGHLIGHTS

- A number of wastewater treatment processes incorporating CWs are reviewed.
- The integrated systems can promote the organic/nutrients/heavy metals elimination and energy recovery etc.
- They present a novel pathway to complement individual drawbacks and simultaneously increase each valuable function.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Available online 12 May 2015

Keywords:
Constructed wetlands
Incorporation
Integration
Energy recovery
Performance intensification
Wastewater treatment process

ABSTRACT

Given their advantages in terms of low-cost and easy-operation, constructed wetlands (CWs) have been thoroughly studied and widely utilized in the treatment of various wastewaters. With the deteriorating environment leading to more stringent discharge standards, including the emphasis on effluent reuse, CW systems operating as standalone technologies are in some cases unable to meet the requirements of these new guidelines despite improvements in design and operational strategies and the utilization of intensified systems. This is the driving force behind the emergence of treatment systems integrating CWs with other treatment technologies to achieve enhanced treatment efficiency or extended treatment goals. These combined/integrated treatment systems could present a novel pathway to tackle the individual drawbacks while simultaneously stabilizing or even improving their existing functions.

The main objective of this paper is to review and summarize the novel combinations of CWs with other treatment technologies to: promote organic and nutrient removal; eliminate persistent organics or heavy metals; recover energy; and other special goals from the published literature worldwide. The review also describes the development direction as well as the challenges for these integrated technologies in the future. It is believed that the review can provide a useful framework for further research in this area.

Contents

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http://dx.doi.org/10.1016/j.cej.2015.05.023
1385-8947/

1. Introduction

Constructed wetlands (CWs) have been widely employed since its first full-scale application in the late 1960s [1]. Considering their low-cost, easy-operation/maintenance, CWs have been extensively applied to treat domestic sewage, agricultural wastewater, industrial effluent, mine drainage, landfill leachate, urban runoff, and polluted river water in the last several decades [2]. It also offers a reliable and suitable treatment process in developing countries and rural areas.

However, CWs also have some intrinsic drawbacks that can limit their application and long-term stability. Among them, substrate clogging is the biggest concern especially when CWs are used in wastewater treatment with high organic and SS loading rates [3]. Moreover, CWs sometimes have low nitrogen removal efficiencies; they may be nitrification limited as a result of low oxygen transfer or denitrification limited due to low amounts of available organics [4], especially under high nitrogen loading rates. Furthermore, some recalcitrant pollutants and heavy metals in industrial wastewater also present challenges to the performance of CWs [5].

With the deteriorating environment and stringent discharge standards, including the emphasis on effluent reuse, CW systems operating as standalone technologies are in some cases unable to meet the requirements of these new guidelines [6] despite improvements in design and operational strategies and the utilization of intensified systems such as flow direction reciprocation, artificial aeration, tidal flow CWs etc. [2]. Therefore, combining or integrating CWs with other existent or emerging technologies, such as membrane bio-reactor (MBR) [7], electrochemical oxidation [8], microbial fuel cells (MFCs) [9] etc. have emerged in recent years with the aim of maximizing the individual advantages in terms of wastewater treatment. These technologies have been proven to be robust in the treatment of specific pollutants and/or as green process for energy recovery although they still have some limitations, as documented in the literature [10,11].

The main objective of this paper is to review and summarize the novel combinations of CWs with other treatment technologies to: promote organic and nutrient removal; eliminate persistent organics or heavy metals; recover energy; and other special goals from the published literature worldwide.

2. Incorporating CWs to enhance organic/nutrients removal

2.1. Coupling with the MBR process

Membrane bio-reactor (MBR) technology is characterized with by treatment efficiency and high quality effluent due to its simultaneous biological treatment and filtration effects [7]. Therefore, it is often utilized for advanced wastewater treatment to achieve water reclamation and reuse [12]. Moreover, compared with conventional wastewater treatment processes (say activated sludge process), MBR has the advantage of removing suspended solids while simultaneously simplifying the whole treatment process by eliminating the need for a secondary clarifier. Various kinds of MBR (both aerobic- and anaerobic-MBR) have been applied in full-scale practice to great effect, especially for high strength industrial wastewater [13,14]. However, MBRs have good removal efficiencies for COD and TSS but can sometimes fail to achieve satisfactory removal of nutrients, especially when low-cost materials are used as the membrane module in order to reduce the investment [15–18].

Therefore, there is a motivation to combine MBR technology with CWs to simultaneously achieve low-cost operation while satisfying effluent quality demands (Fig. 1(a)). As such, the effluent of the MBR can be further polished in CWs while the MBR, acting as "pre-treatment" step, could protect CWs from clogging and prolong their lifetime. Kong et al. [18] studied the performance of a dynamic membrane bioreactor (DMBR, ceramic membrane) incorporating an integrated vertical constructed wetland (IVCW) for treating synthesized municipal wastewater. The best performance for COD, TN, TP and turbidity removal efficiencies were 93.3%, 93.0%, 90.4% and 99.1%, respectively. Although only 31.2% of COD was removed by the DMBR, it contributed significantly to removing turbidity (50%), which could protect the CW from clogging. Due to the lack of the required, specific conditions for TN and TP removal, the DMBR had a limited contribution to nutrients removal while the ensuing IVCW contributed about 80% and 70% to TN and TP removal, respectively. Earlier, Xiao et al. [19] reported a trial for combining a submerged membrane bioreactor (SMBR, hollow fiber membrane) and a CW to treat high strength wastewater with COD, TN, TP and NH_4^+ concentrations of 1008.08 ± 63.50 mg/L, 95.22 ± 3.22 mg/L, 5.76 ± 0.38 mg/L and 62.10 ± 2.6 mg/L, respectively. Despite high pollutant concentrations in the influent, the combined process still achieved 98%, 96%, 80% and 99% removal for COD, TP, TN and NH_4^+, respectively, to which the SMBR contributed about 95%, 74%, 68.5% and 92% while the CW removed 2.5%, 24%, 26% and 7.2%, respectively. This had the combined effects of mitigating the potential for clogging in the CW and also reducing the size requirements of the CW. In terms of wastewater treatment performance, the SMBR has a competitive advantage to DMBR and, furthermore, has a lower risk of fouling when compared with DMBR. Although, to-date there are limited studies regarding this novel combination, it offers a potential alternative to conventional treatment process.

2.2. Coupling with anaerobic processes

The advantages of applying anaerobic technologies to wastewater treatment lie in their energy (biogas) production, operational simplicity and low mass production, especially in tropical areas with a warm climate [20–22]. Many different configurations of anaerobic reactors have been well developed, such as anaerobic filter (AF), fluidized bed reactor (FBR), up-flow anaerobic sludge blanket (UASB), anaerobic baffled reactor (ABR) etc. In spite of the significant advantages, the effluent of single-step anaerobic reactors often does not meet the discharge standard, especially in terms of nutrient levels and pathogens. As summarized by