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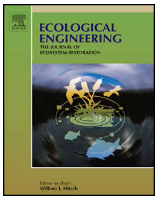

Review

Constructed wetlands for saline wastewater treatment: A review

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ABSTRACT

Saline wastewater originating from sources such as agriculture, aquaculture, and many industrial sectors usually contains high salts and other contaminants, which adversely affect both aquatic and terrestrial ecosystems. Therefore, the treatment of saline wastewater, for both salts and specific contaminant removal, has become a necessary task in many countries. Conventional methods (e.g., using physico-chemical equipment, biological reactors, or a combination thereof) are feasible for treating most saline wastewaters (sometimes only for the removal of contaminants rather than the salts, e.g., biological reactors). However, the high cost of these techniques limits their application in many areas, especially in developing countries. For this reason, constructed wetlands (CWs) have been successfully used for treating a wide variety of wastewaters, and are eco-friendly and cost effective, and provide a potential alternative technology for saline wastewater treatment. The current review illustrates the latest knowledge on the use of CWs for treating saline wastewater. Though the function of plants and microorganisms in CWs is sometimes inhibited by salts, acceptable treatment effectiveness can still be achieved by screening halophyte, optimizing wetland structure and operation parameters, and by exploring the application of halophilic microorganisms. Factors influencing the effectiveness of CWs for saline wastewater treatment include; wetland structures, operation parameters, water pH, and temperature. Future studies are recommended on the removal of different types of target contaminants, strategies for strengthening the purification process, and on conducting large-scale field experiments under real-world conditions.

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1. Introduction

With the development of industry, agriculture, and aquaculture, various types and large amounts of salts are consequently produced, and/or are naturally occurring. These salts (referred to cations and anions, but heavy metals are not included) are discharged together with other contaminants (e.g., organic matter and heavy metals) as saline wastewater (Lefebvre and Moletta, 2006). The continuously increasing discharge of saline wastewater without any treatment has been threatening aquatic, terrestrial, and wetland ecosystems. The treatment of saline wastewater, for both salts and specific contaminants removal, is therefore an urgent task in many countries. Conventional treatment plants offer feasible methods for treating saline wastewater. However, most of these methods use sophisticated equipment, which require large economic investments and consume vast amounts of energy. Moreover, these conventional methods are ineffective in controlling diffuse pollution (usually refers to non-point source pollution) (Wu et al., 2013a,b). For the treatment of saline wastewater, constructed wetlands (CWs) outperform many other processes. They have received increasing attention in recent years, especially in developing countries, because of their minimal costs, convenient operation, eco-friendly characteristics, and aesthetic value (Zhi and Ji, 2012; Li et al., 2007; Katsenovich et al., 2009; Zhang et al., 2009).

There are a few documented cases where CWs have been successfully used for treating saline wastewater originating from multiple sources such as industrial sectors and mariculture (Vymazal, 2014). However, a comprehensive assessment regarding the feasibility of using CWs for treating saline wastewater is not available. In addition, the key purification mechanisms of CWs for specific contaminants under saline conditions, and the interaction among salts, target contaminants, and wetlands remains unclear. Therefore, the objectives of this review are: (1) list the major sources of saline wastewaters and their environmental impacts; (2) summarize the function and mechanisms of plants, microorganisms, and substrates in CWs for saline wastewater treatment; and (3) discuss the factors that can potentially influence the efficiency of CWs. This review paper offers guidance for subsequent studies on the treatment of various saline wastewaters by CWs.

2. Source of saline wastewater

The composition and concentration of saline wastewaters depend on their sources. The major sources of saline wastewater include; agricultural drainage in regions exhibiting soil salinization problems, aquaculture in coastal zones, various industrial sectors, and other secondary sources such as concentrated effluent originating from membrane or electrodialysis equipment (Xiao and Roberts, 2010; Vymazal, 2014).

Soil salinization enhanced by high rates of evapotranspiration is a prominent problem in arid and semi-arid regions (Williams, 1999; Jayawardane et al., 2001; Freedman et al., 2014). Currently, about 7% of the world's land surface and over 20% of the world's agricultural land are threatened by salinization (Li et al., 2014; Zhang et al., 2015). Saline farmland becomes a source of saline wastewater when excessive irrigation or rainfall occurs. For example, agriculture activities were shown to contribute to saline inland water in Australia (Williams, 2001). The drainage water originating from saline farmland carries not only salts (carbonates, sulfates, chlorides, nitrates, and borates), nitrogen (N), and phosphorus (P) from chemical fertilizers, but also organics (e.g., non-degradable pesticides or herbicides, and degradable humus) (Jiang et al., 2006; Wauchope, 1978; Beltrán, 1999; Ghobadi Nia et al., 2010; Sun et al., 2012). Generally, the total level of soluble salts is characterized or measured as an electrical conductivity (EC) value or total dissolved solids (TDS) concentration. In the Arys Turkestan Canal area of southern Kazakhstan, a TDS value exceeding 1200 mg L^{-1} was observed for drainage water from irrigated agriculture with sodium (Na^+) and bicarbonate(HCO_3^-) ions as dominant salt constituents (Karimov et al., 2009). A TDS of above 700 mg L^{-1} with Na^+, CO_3^{2-},and HCO_3^- ions as the major salt during different growth periods of rice in a year was reported in an agricultural drainage channel surrounding Chagan Lake, located in the western Jilin Province of China (Yang et al., 2015). A high salinity level (EC) of 15.2 mS cm^{-1} caused by sulfate-dominated salts, with values of 14.5 mg L^{-1} for boron and 1.18 mg L^{-1} for selenium, was found in drainage waters originating in the western San Joaquin Valley of Central California (Bañuelos and Lin, 2006). An average TDS of 1800 mg L^{-1} and three pesticides (diazinon, methomyl, and acephate) with maximal values of 0.1, 1.5, and 1.7 $\mu g\ L^{-1}$, respectively, were detected in an inlet of a wetland in the Salinas Valley, CA, USA (Krone-Davis et al., 2013).

Aquacultural activities have been thriving during the last decade with increasing demand for fish, shell fish, crustaceans, and other fishery products. China is one of the top finfish (e.g., *Cyprinus carpio*) and shellfish (e.g., *Mytilus edulis* and *Brachyura*) producing countries in the world (Cao et al., 2007; Xie et al., 2013; Cao et al., 2015). The size of China's mariculture as a sub-sector of aquaculture has an upward trend although less than that for freshwater aquaculture (Cao et al., 2007). Fish farming remains a highly diverse industry in China and mariculture systems usually operate in coastal waters at depths of less than 15 m in intertidal mudflats, shallow seas, and bays. In China, offshore mariculture has expanded to depths of up to 50 m and an area of more than 1,286,000 ha (Feng et al., 2005). Coastal mariculture requires sea water and also produces large volumes of wastewater containing salts and various contaminants (Brown et al., 1999). Organics, suspended solids (SS), N, P, and salts are generally considered to be the major contaminants, although the types and concentrations of contaminants in maricultural wastewater depend on breeding species, culture methods, feed quantity, and sanitary control (McIntosh and Fitzsimmons, 2003). It is noteworthy that antibiotics such as flumequine, oxytetracycline, and thiamphenicol, which are applied for preventing bacterial infection, are typical organic pollutants also found in maricultural wastewater (Dosdat et al., 1995; Davidson et al., 2008). In addition to coastal mariculture, seafood processing industries such as canning also use large amounts of saline wastewater. High levels of organics (protein and lipids), phosphates, nitrates, and solids, with salinities ranging from 15 to 45 mS cm^{-1}, were observed in this type of wastewater (Zhao et al., 2010; Chowdhury et al., 2010). For example, high concentrations of sea salts (Cl^-: 8–19 g L^{-1}; Na^+: 5–12 g L^{-1}; SO_4^{2-}: 0.6–2.7 g L^{-1}) in wastewater from some fish-canning factories were reported by Mendez et al. (1995).

Many industrial sectors (e.g., tanning, textile-dyeing, pulp and paper production, and mining) are likely to generate highly saline wastewater that contains more complex contaminants than agricultural or aquacultural sources. Tannery activities, including soaking, pickling, and tanning processes (Sundarapandiyan et al., 2010), usually generate effluent containing organics, SS, dissolved solids (mainly Cr and acidic ions), ammonia, organic nitrogen, and other specific pollutants (e.g., sulfide) (Roš and Gantar, 1998; Song et al., 2004). Among those contaminants, about 40% of the applied total Cr salts remain in the liquid wastes after the tanning processes (Fabiani et al., 1997). Chromium concentrations of 1.02 ± 0.13 to 1.56 ± 0.06 mg L^{-1} and TDS values of 65.4 ± 13.87 to 1281.1 ± 0.96 mg L^{-1} were reported by Akan et al. (2007) in five tanneries in the Kano metropolis, Nigeria. Sundarapandiyanet al. (2010) summarized values of TDS, Cl^-, and BOD in soaking wastewater as 22,000–33000, 15,000–30,000, and 3000–6000 mg L^{-1}, respectively. The corresponding values in pickling wastewater were 29,000–70,000, 20,000–30,000, and