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Review

Constructed wetlands for wastewater treatment in cold climate — A review

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ABSTRACT

Constructed wetlands (CWs) have been successfully used for treating various wastewaters for decades and have been identified as a sustainable wastewater management option worldwide. However, the application of CW for wastewater treatment in frigid climate presents special challenges. Wetland treatment of wastewater relies largely on biological processes, and reliable treatment is often a function of climate conditions. To date, the rate of adoption of wetland technology for wastewater treatment in cold regions has been slow and there are relatively few published reports on CW applications in cold climate. This paper therefore highlights the practice and applications of treatment wetlands in cold climate. A comprehensive review of the effectiveness of contaminant removal in different wetland systems including: (1) free water surface (FWS) CWs; (2) subsurface flow (SSF) CWs; and (3) hybrid wetland systems, is presented. The emphasis of this review is also placed on the influence of cold weather conditions on the removal efficacies of different contaminants. The strategies of wetland design and operation for performance intensification, such as the presence of plant, operational mode, effluent recirculation, artificial aeration and in-series design, which are crucial to achieve the sustainable treatment performance in cold climate, are also discussed. This study is conducive to further research for the understanding of CW design and treatment performance in cold climate.

Contents

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Introduction

Given the more restrictive economic resources to implement and operate conventional wastewater treatment infrastructures and facilities, the development of alternative, small-scale and innovative wastewater treatment technology has gain increasing attention. Constructed wetlands (CWs) are engineered systems designed and constructed to utilize the natural functions of wetland vegetation, soil media, and their associated microbial associated assemblages for wastewater treatment within a more controlled environment (Kadlec and Knight, 1996). Because of their high pollutant removal efficiency, easy operation and maintenance, low cost, good potential of water and nutrient reuse, tolerance to high variability, and function as significant wildlife habitat, CWs have been recognized as a sustainable wastewater management option (Mitsch and Gosselink, 2000; Kadlec and Wallace, 2008).

The best prospects for successful wetland treatment should be in the tropical or subtropical regions of the world, and application of CW for wastewater treatment in frigid climate presents special challenges (M?hlum and Jessen, 2003; Zhang et al., 2014a, 2014b). Nevertheless, over the past decades, studies in North America and Europe showed that wetland treatment may be feasible also in cold climate (M?hlum and Stålnacke, 1999; Tunçsiper et al., 2015). According to Wittgren and M?hlum (1997), cold climate is taken as equivalent to “cold temperate” climate, where the coldest month has a man temperature blow −3°C and the warmest a mean above 10°C. In cold climate, CWs have been practised mainly for the treatment of municipal sewage (M?hlum and Stålnacke, 1999; Jenssen et al., 2005). Recently, the application of CWs has been increasingly extended to address other types of wastewaters including industrial wastewaters (Comino et al., 2011), agricultural runoff (Thoren et al., 2004; Feng et al., 2012; Tunçsiper et al., 2015; Zhang et al., 2016), lake waters (Martín et al., 2013), landfill leachate (Nivala et al., 2006; Speer et al., 2012), stormwater runoff (Heyvaert et al., 2006), and peat extraction effluent (Postila et al., 2015).

In treatment wetlands, the pollutant removal efficiency varies considerably (Vymazal, 2007; Zhang et al., 2014a). Such variability can be traced back to the complex combination of physical, chemical and biological processes for contaminant removal, which depends on a number of variables including wastewater application rate, organic loading rate, hydrologic regime, hydraulic detention time (HRT), operational mode (batch or continuous mode), the presence of vegetation, and plant species (Kadlec and Wallace, 2008; Gersberg et al., 1986; Brix, 1997). Additionally, a variety of pollutant removal of processes, such as sedimentation, filtration, precipitation, volatilization, adsorption, plant uptake, and various microbial processes, is generally directly and/or indirectly influenced by the different internal and external environment conditions such as temperatures (Stottmeister et al., 2003).

However, there still exists uncertainty about how temperature can affect contaminant removal efficiencies and treatment processes. In general, wetland treatment of wastewater relies largely on biological and biochemical processes, and reliable treatment is often a function of climate conditions (M?hlum and Jessen, 2003). Nutrient uptake by plants and microbial transformation of wastewater components and plant litter in wetlands are both directly and indirectly affected by climatic conditions (Wittgren and M?hlum, 1997). Direct influence means that the temporal variations in wetland performance depend often on the plant physiology, which is governed by solar radiation and temperature (Akratos and Tsihrintzis, 2007). Indirect influence refers to the dependence of biological and biochemical processes on physical conditions; for instance, the low temperature restrains microbial activities and reduces bacterial growth, resulting in low purification efficiency (Werker et al., 2002). These factors make wetland application more dependent on climatic conditions than conventional wastewater treatment

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