Journal of Cleaner Production 127 (2016) 325–330

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Impacts of different media on constructed wetlands for rural household sewage treatment

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ARTICLE INFO

Article history:
Received 6 October 2015
Received in revised form
29 March 2016
Accepted 29 March 2016
Available online 27 April 2016

Keywords:
Rural domestic sewage
Constructed wetland
Dissolved oxygen
Media filler
Aquatic plants

ABSTRACT

Constructed wetland systems have been used for treating a variety of household and industrial wastewater; they are a wastewater treatment technology that has high economic efficiency and environmental effectiveness, especially for sewage treatment in rural areas. Medium filler plays an important role in wetland sewage treatment processes. By carrying out a problem analysis of the ineffective operation and treatment of traditional wetlands, this paper designs different constructed wetland fillers to treat rural household sewage. Using the same plants, this paper chooses four different fillers, namely maifanite, steel slag, bamboo charcoal and limestone as substrates to build constructed wetland systems, and studies rural household sewage treatment in order to examine their effects on the degradation of pollutants. The results show the removal efficiencies obtain good effect. The theoretical maximum adsorption capacities of all these media are ordered as: maifanite > steel slag > bamboo charcoal > limestone. The effluent water quality meets the first class A standard of the "Discharge standard of pollutants for municipal wastewater treatment plant" (GB18918-2002). The selection of medium has an important significance for the operating results of constructed wetland sewage treatment systems.

1. Introduction

For a long time, due to the shortage of funding for water pollution treatment and a weak awareness of water resources and environmental protection in rural China, household sewage has been directly discharged in rural areas without treatment, becoming the main reason for the decline in water quality of river and lake waterbodies, groundwater and water resources (Yang et al., 2015; Zhang et al., 2015). Therefore, it has become of urgent practical significance to study rural household sewage treatment techniques, explore suitable treatment models and promote the construction of a new socialist countryside.

Constructed wetland sewage treatment systems are derived from the simulation of natural wetlands; they use the triple synergistic effects of natural ecosystems in physical, chemical and biological states to achieve sewage purification (Zhi and Ji, 2012; Grossmann, 2012). Depending on the length-to-width ratio and ground slope, particles fillers of a certain size (such as gravel, soil, peat, etc.) and aquatic plants, are used together to constitute the constructed wetland treatment system (Saumya et al., 2015; Lam et al., 2015). The aquatic plants generally used are beautiful and have good processing qualities (Boonsaner and Hawker, 2015; Mackul'ak et al., 2015), a high survival rate, strong water resistance, long growing seasons and high economic value (such as reeds, caltrops, iris, etc.). Together with animals and microorganisms that live in the water and filler, they form a unique flora and fauna environment. When the sewage flows through the patch surface and the gaps between patch fillers, an efficient purification can be achieved through filtration, adsorption, sedimentation, ion exchange, absorption by plants, microbial decomposition, etc.

Abbreviation: BOD, Biochemical Oxygen Demand; HRT, Hydraulic retention time; COD, Chemical Oxygen Demand; TP, Total phosphorus; TN, Total nitrogen; SS, Suspended solids.

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http://dx.doi.org/10.1016/j.jclepro.2016.03.166
0959-6526/

The study of constructed wetlands has its origin in the study of wetlands generally (Moreno et al., 2007; Gao et al., 2007). Constructed wetland is a type of sewage treatment process that began to develop in the 1970s (Hattermann et al., 2006; Vymazal et al., 2007). The constructed wetland treatment system artificially batches sewage with land that is usually in a submerged state and has aquatic plants growing (such as reeds, cattails, etc.), the sewage along a certain direction of flow is purified under the synergistic effects of water-resistant plants, soil and microorganisms (Benmoussa et al., 1997; Tachikawa and Yamanaka, 2014; Oshima et al., 2015). Due to the addition of human technology to their guidance, design and operation management, constructed wetlands have wider range of applications, more processing power and with improved treatment efficiency. In recent years, along with economic development and the increasing depletion of water resources, constructed wetlands have attracted the attention of most of countries around the world due to their high efficiency, low cost and excellent performance.

Constructed wetland systems have been used for treating numerous forms of wastewaters, mainly including industrial, rural household, urban household and nonpoint-source pollution, especially urban household sewage and nonpoint-source pollution (Matamoros and Salvadó, 2012; Galanopoulos et al., 2013; Shao et al., 2013). At present, constructed wetlands have been developed into a sewage treatment technology that has high economic efficiency and environmental effectiveness that is particularly suited to sewage treatment in rural areas.

The key elements of the applications of constructed wetlands in sewage treatment are plants and media (Dordio et al., 2007; Dordio and Carvalho, 2013; Wu and Zhang, 2015). Medium means filler can be used to intercept significant pollutants in sewage through sedimentation, filtration and adsorption. It is also the substance wherein the other active elements (plants and microorganisms) of constructed wetlands survive. Therefore, the selection of filler plays a key role in constructed wetlands to provide effective water purification. At present, typical constructed wetland fillers are zeolite, vermiculite, gravel, limestone, coal ash, slag, grit and soil, clay minerals and some industrial byproducts. Medium is the carrier in constructed wetland; its own physical and chemical properties may directly affect the sewage treatment efficiency of the whole system. In addition, when the inside of the patch is filled with a porous medium that has a large specific surface area, this can improve the hydraulic and mechanical properties of the wetland and provide microorganisms with a greater surface area for adhesion, enhancing the pollutant removal capacity of the system. Therefore, the selection of medium has great significance for the operational efficiency of the constructed wetland sewage treatment system.

The filler medium plays an important role in wetland processes for sewage treatment. At present, the wetlands treatment process makes wide use of grit sands, soil, gravels and other substrate fillers. The investment is more efficient (Verlicchi and Zambello, 2014 and Zhang et al., 2009), but the nitrogen and phosphorus removal efficiencies of these fillers are not ideal; therefore, experts have constantly developed new wetland fillers and carried out different levels of tests. Smol et al. (2015) use gravel patch and gravel-soil patch as constructed wetland fillers to test household sewage treatment. The results show the phosphorus removal efficiency of gravel-soil patch to be very good but that the ammonia nitrogen removal efficiency is much less so. An et al. (2014) show that natural zeolite can effectively absorb ammonia nitrogen in tap water, thus effectively reducing its ammonia nitrogen concentration. Hussain and Aziz (2011) have studied the capacity of three constructed wetlands namely zeolite, zeolite-limestone and limestone. The results show that the ammonia removal efficiencies of zeolite and zeolite-limestone wetland systems are very good. At the same time, Cui et al. (2013) have compared the removal efficiencies of different wetland fillers, concluding that the ammonia nitrogen removal efficiency of zeolite is significantly higher than that of gravel, but with a phosphorus removal efficiency of only 20%. Vohla et al. (2011) use fly ash as a substrate filler in a wetland system to carry out an experimental study on household sewage, and compare their findings with the operating situations of gravel filler wetland systems. The results show that the removal efficiencies of a fly ash wetland system on nitrogen, phosphorus and organic substances in household sewage are good, of which ammonia nitrogen removal is clearly much higher than that with the gravel filler wetland system. Cui and Ouyang (2015) use coal ash and artificial soil as the filler in a subsurface-flow wetland treatment system to treat the effluent of a septic tank to demonstrate experimentally that the effluent concentration of TP meets the discharge standards. Zhang et al. (2015) also successfully use zeolite to remove ammonia nitrogen in urban sewage.

By carrying out a problem analysis of the ineffective operation and treatment of traditional wetlands, this experimental study designs different constructed wetland fillers for rural household sewage treatment. Using the same plants, four different fillers of maifanite, steel slag, bamboo charcoal and limestone are tested as substrates in building constructed wetland systems, and rural household sewage treatment is studied in order to examine its efficiency on the degradation of pollutants.

2. Experimental section

2.1. Experimental apparatus and methods

The experiment uses stepcase constructed wetlands, which is a type that belongs to composite vertical upward-flow subsurface-flow constructed wetlands. The structure is shown in Fig. 1 (see Lu et al., 2015. The trapezoidal concrete pond has a height of 160 cm, a longer base length of 3 cm and shorter base length of 1.7 cm; the total thickness of the substrate layer is 80 cm, and there is a 40 cm thick soil layer on the top of the substrate layer. The influent reservoir baffle has a height of 140 cm and the influent sediment pond baffle has a height of 120 cm. A large gravels layer stands beneath the influent sediment pond baffle, and there is a portion of connectivity between the influent channel and the large gravel layer. The effluent sediment pond baffle has a height of 100 cm and the effluent reservoir baffle has a height of 80 cm.

The working principle of this apparatus is that the rural household sewage enters into the concrete pond through the influent pipe, after which it first enters into the sewage sediment pond for sedimentation, and then overflows from the influent reservoir baffle to penetrate into the substrate layer through the influent channel. This means that, when it penetrates into the substrate layer from the beneath of the influent sediment pond, it goes through the substrate filler layer and soil layer from bottom to top and, after the filtration process, overflows through the effluent sediment pond baffle into the effluent sediment pond, before overflowing again into the effluent reservoir when the effluent sediment pond is full. There are aquatic plants on the wetland soil layer. Perforated tubes and sampling tubes are vertically set up along the middle of the patch in order to take water samples and measure dissolved oxygen, temperature, pH and other parameter values within the wetlands. The apparatus operated from April 2012 to August 2012, running in good condition.

The hydraulic retention time (HRT) in this experiment was set to a 7 day period. The COD, turbidity, $NH3-N$, TN and TP of influent and effluent water was measured 7 consecutive times, and their removal efficiencies finally calculated.