The Removal Effect of Organic Pollutants by Different Fillers in Constructed Rapid Infiltration System

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Abstract. In recent years, the concept of ecological treatment of rural domestic sewage and tail water reuse has been strongly advocated by the Ministry of Ecology and Environment. Constructed rapid infiltration (CRI) system is a low-cost and suitable ecological sewage treatment measure in rural areas. There are many kinds of filter materials in CRI system, but there are few reports on the research of filter materials based on Farmland Irrigation Standard (GB18918-2002) as the effluent discharge standard. In this study, red sandy soil, black volcanic rock, red volcanic rock, slag and biological ceramsite were selected as the filter media of CRI system, and five CRI systems were constructed. Under the condition of hydraulic loading rate (HLR) of 1 m·d−1 and test period of 30 days, the removal efficiencies for chemical oxygen demand (COD) and five-days biochemical oxygen demand (BOD_5) by each CRI system were studied, and the best filter media for organic pollutants removal was finally selected. The results show that red volcanic rock has the best removal efficiency for COD and BOD_5. The effluent concentrations of COD and BOD_5 are 43.8 mg/L and 30.2 mg/L, respectively, and the corresponding removal rates are 72.1% and 74.4%, respectively. The effluent can meet the standards of Class B and Class A vegetables in Farmland Irrigation Standard, respectively. This study provided a theoretical basis for the rational selection of filter material in practical engineering application of CRI system to improve the removal performance of organic pollutants.

Keywords: Constructed rapid infiltration system · Fillers · COD · BOD_5

1 Introduction

In China, point source and non-point source pollution has become a growing concern, especially the discharge of domestic sewage in rural areas. It is reported that the annual discharge of domestic sewage in villages and towns in China has reached 20 billion cubic meters [1]. However, most rural areas in China are not equipped with perfect drainage pipe network and sewage treatment system, so that sewage is directly discharged into the

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surrounding receiving water without treatment. Rural domestic sewage contains a large amount of organic pollutants, such as chemical oxygen demand (COD), five-days biochemical oxygen demand (BOD_5), etc. If it is discharged directly without treatment, it will not only threaten the safety of ecology and water environment, but also cause potential safety hazards to rural water sources, aggravate the crisis of fresh water resources, make farmland irrigation unable to be effectively guaranteed, and affect the survival and development of farmers [2, 3]. Therefore, it is urgent to take an eco-friendly sewage treatment technical measure to treat rural domestic sewage.

In recent years, the Ministry of Ecology and Environment and the Ministry of Housing and Urban-Rural Development jointly issued the Notice on Accelerating the Formulation of Local Rural Domestic Sewage Treatment Discharge Standards, which proposed: 1) Promote the extension of sewage pipe network to villages; 2) Encourage the adoption of ecological treatment technology, and require strengthening the source reduction of domestic sewage and the recycling of tail water. In rural areas, because of the complexity of terrain and the dispersion of villagers' residences, the cost and difficulty of building sewage pipe network are increased. Thus, the method of adopting ecological treatment technology is more suitable for rural areas, and farmland irrigation is a very suitable way of sewage recycling in rural areas.

Constructed Rapid Infiltration (CRI) system is a kind of ecological wastewater treatment technology with low cost, no energy consumption and good water purification effect. It is developed from the traditional Rapid Infiltration (RI) system and uses the medium with better permeability to replace the natural soil layer. It is especially suitable for the treatment of rural domestic sewage [4, 5]. Many scholars have carried out a large number of studies on the water purification effect of CRI system. 1) Most of the studies focus on the removal of nitrogen and phosphorus by CRI system [6–8], However, the nitrogen and phosphorus substances rich in sewage can be used as nutrients of crops, which is conducive to the growth of crops and plants. Hence, treating rural domestic sewage to meet the Farmland Irrigation Standard (GB5084-2005) and reusing it in farmland not only "turns waste into wealth" but also conforms to the sewage reuse concept mentioned in the above notice; 2) A few scholars have studied the removal efficiency of organic pollutants by CRI system. Shi X et al. [9] investigated the treatment effect of various fillers on sewage, and the results showed that the COD removal rate of anthracite, round ceramic and gravel only reached 50%, indicating a phenomenon of low removal rate. 3) In existing studies, most of the sewage treatment discharge standards after CRI system treatment are Urban Sewage Treatment Plant Pollutant Discharge Standards (GB18918-2002). However, few reports have investigated the effect of CRI systems on the removal of COD and BOD_5 from wastewater using the Agricultural Irrigation Standard (GB5084-2005) as the sewage discharge standard.

In this study, five different filter media were selected as the filter media of CRI system, namely red sandy soil, black volcanic rock, red volcanic rock, slag and biological ceramsite, and five test column of CRI system were built to investigate the changes of COD and BOD_5 concentration and removal effect of the inlet and outlet water of CRI system with different kinds of filter media, aiming to select the filter media with the best performance in the removal of COD and BOD_5, which can provide the basis for improving the removal of organic pollutants in CRI systems, thus promoting the practical application of CRI systems in the field of rural domestic wastewater treatment.

2 Materials and Methods

2.1 Test Process and Device

The experimental procedure and installation of the CRI system are shown in Fig. 1. First, the test water was taken from the inlet of the domestic wastewater treatment station on the campus of Xiamen Institute of Technology (Fig. 1A). Secondly, a polyethylene plastic box (Fig. 1B) was used to contain the collected domestic wastewater and then transferred to the laboratory for use. Then, a peristaltic pump (Fig. 1C) was used to lift the domestic wastewater in the polyethylene plastic box to the water distribution port of the CRI system test column (Fig. 1D). Finally, the COD and BOD_5 concentrations in the inlet and outlet water of the CRI system test column were measured.

CRI system test column made of plexiglass, column height of 60 cm, inner diameter of 9 cm, outer diameter of 10 cm, filter material thickness of 30 cm. The water pipe is used to distribute water evenly to the CRI system, and the water intake can be controlled by adjusting the speed of the peristaltic pump. The water outlet is located at the bottom of the test column, and each column is equipped with one water outlet.

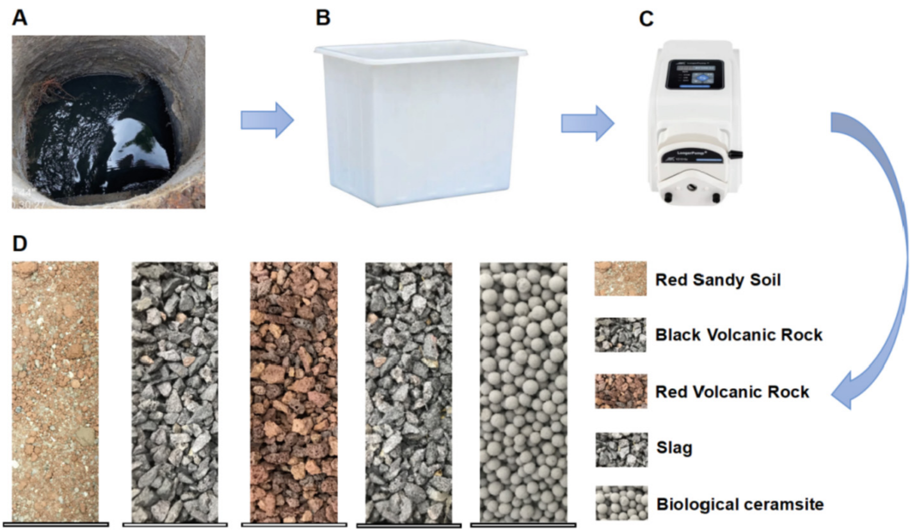

Fig. 1. Flow chart of CRI system for treatment of domestic sewage (A: inlet of domestic sewage treatment station of Xiamen University of Technology; B: Sewage storage tank for collecting domestic sewage at the inlet; C: Peristaltic pump, used to transfer sewage and distribute water to CRI system; D: CRI system test column, the thickness of the filter material is 30 cm)

2.2 Test Filter Material Type

There are five kinds of filter media in this experiment, which are: 1) red sandy soil, a kind of composite filter media which is evenly mixed by two kinds of filter media whose mass ratio is red loam: miscellaneous sand = 1: 1, and the permeability coefficient is 2.78 * 10^{-4}; 2) Black volcanic rock, an irregular porous particle filter material with black appearance, with a particle size of 2–4 mm and a permeability coefficient of 4.88 * 10^{-3}; 3) Red volcanic rock, an irregular porous particle filter material with red appearance, with a particle size of 2–4 mm and a permeability coefficient of 3.94 * 10^{-3}; 4) slag, a new filter material with high removal efficiency of suspended solids, large sludge interception load and good prospect of popularization and application, with a particle size of 2–4 mm and a permeability coefficient of 4.03 * 10^{-3}; 5) biological ceramsite, a new biofilm carrier filter material with the advantages of light weight, large specific surface area and strong adsorption capacity, with a particle size of 2–4 mm and a permeability coefficient of 3.98 * 10^{-3}.

2.3 Inlet Water Condition and Inlet Water Quality

The test inlet water was taken from the inlet of the campus sewage treatment station, and the specific inlet water concentration range was as follows: COD = 126.8 ~ 233.3 mg/L, BOD_5 = 89 ~ 104 mg/L. Five CRI system test columns with different filter media were used to operate under the same inflow conditions, with hydraulic loading rate of 1 $m{\cdot}d^{-1}$ and daily inflow of 6.4 L. The total duration of the experiment was 30 days, and every day was divided into three cycles of water distribution, each cycle was run for 2 h, respectively from 8:00 to 10:00, 12:00 to 14:00, and 18:00 to 20:00, and the wet-dry ratio was 1: 4. The inlet and outlet water quality of CRI system test column was monitored every 2 days to investigate the removal effect of different filter materials on COD and BOD_5 in domestic sewage. The daily water inflow of CRI system was calculated with Eq. (1).

$$Q = HLR * \pi R^2 * T \tag{1}$$

Where, Q is the daily water inflow of CRI system test column (m^3); HLR is Hydraulic loading rate ($m{\cdot}d^{-1}$). R is the radius of the test column (m); T is time (d).

2.4 Testing Items and Methods of Water Quality Indexes

Test items of inlet and outlet water quality indexes include COD and BOD_5. The detection method of COD was rapid digestion spectrophotometry (HJ/T 399-2007), and the detection instruments were Lianhua 5B-1 (V8 version) digestion device and Lianhua 5B-3B (V8 version) multi-parameter water quality tester. BOD_5 was detected by dilution and inoculation method (HJ 505-2009) with BODTrak biochemical oxygen demand analyzer.

3 Results and Discussion

3.1 Removal Effect of COD by Different Filter Materials

During the whole test period, the removal of COD by CRI systems with different filter media is shown in Fig. 2. As can be seen from Fig. 2A, The influent COD concentration of CRI system ranged from 126.8 mg/L to 233.3 mg/L, The average concentration of effluent after the CRI system of various filter materials runs stably is as follows: red volcanic rock (43.8 mg/L), slag (60.6 mg/L), red sandy soil (79.3 mg/L), black volcanic rock (83.7 mg/L), and biological ceramsite (123.8 mg/L), that is, the order of removal efficiency of COD by five filter media is red volcanic rock > slag > red sandy soil > black volcanic rock > biological ceramsite, so red volcanic rock has the best removal efficiency of COD, and only the effluent of red volcanic rocks can meet the irrigation standard of Class B vegetables in Farmland Irrigation Standard (GB5084-2005).

Figure 2B shows the removal rates of COD by different filter materials. After stable operation, the corresponding removal rates are: red volcanic rock (72.1%) > slag (60.9%) > red sandy soil (46.3%) > black volcanic rock (43.5%) > biological ceramsite (23.6%). The COD removal rate curve of red volcanic rocks shows a gradual upward trend as a whole; From the first day to the 20th day of the experiment, the COD removal rate curve fluctuated. From the 20th to 30th days, the removal rate of COD began and finally stabilized, because the removal of COD in the early stage of the experiment depended on the adsorption of red volcanic rock, and in the later stage, due to the gradual formation and stability of biofilm, adsorption and biodegradation contributed to the decomposition of COD [10]. The COD removal rate curves of slag and red sandy soil are similar to those of red volcanic rock, with a trend of "rising first and then stabilizing", but the COD removal rate of red sandy soil is lower than that of slag. The removal of COD by black volcanic rocks is "stable-fluctuating-stable again", COD removal rate did not increase in the later stage of the experiment, It is related to the adsorption performance of black volcanic rock, Because the adsorption sites of black volcanic rock are few, with the experiment, the adsorption sites on the surface of filter media are gradually occupied, resulting in the decrease of adsorption performance, so that the removal of COD in the later stage of the experiment mainly depends on the degradation of microorganisms, so the removal of COD in the early and later stages of the experiment depends on the adsorption and microbial degradation of black volcanic rock respectively. The COD removal rate curve of biological ceramsite showed a downward trend as a whole, Because the surface of biological ceramsite is spherical and smooth, which is not suitable for the growth of microorganisms, it is difficult to form and stabilize biofilm, so its removal of COD only depends on adsorption, but with the experiment, the adsorption gradually weakens, resulting in a significant reduction in removal rate and poor COD removal effect.

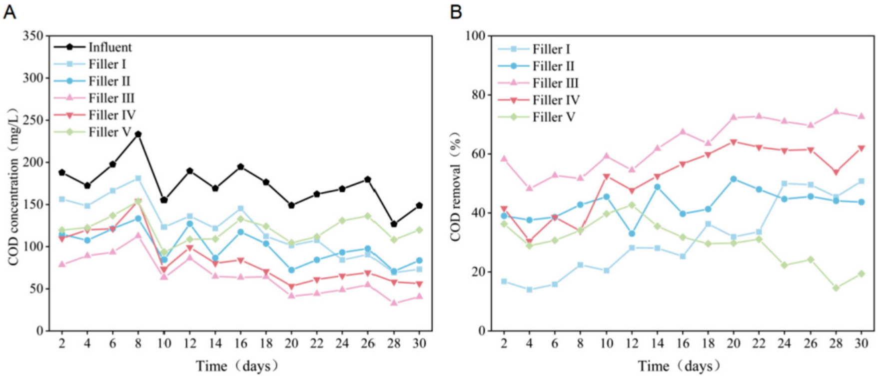

Fig. 2. The removal effect of different filter materials on COD.

3.2 Removal Effect of BOD_5 by Different Filter Materials

Figure 3 shows the removal of BOD_5 by five filter media. As shown in Fig. 3A, The influent BOD_5 concentration of each filter material in CRI system ranges from 89 mg/L to 104 mg/L (average concentration is 95.5 mg/L), The effluent concentrations are red sandy soil (44–72 mg/L), black volcanic rock (56–74 mg/L), red volcanic rock (22–48 mg/L), slag (30–60 mg/L) and biological ceramsite (67–80 mg/L), and the corresponding average concentrations after stabilization are red sandy soil (54.0 mg/L), black volcanic rock (63.8 mg/L), red volcanic rock (30.2 mg/L), slag (42.3 mg/L) and biological ceramsite (73.8 mg/L), respectively. That is to say, red volcanic rock has the best removal effect on BOD_5, and only the effluent of red volcanic rock can meet the irrigation standard of Class A vegetables in Farmland Irrigation Standard (GB5084-2005).

As shown in Fig. 3B, after the CRI system with five filter materials runs stably, the removal rates of BOD_5 are red sandy soil (49.8%), black volcanic rock (36.6%), red volcanic rock (74.4%), slag (63.6%) and biological ceramsite (23.1%). The BOD_5 removal rate curves of red sandy soil, red volcanic rock, black volcanic rock and slag all show a

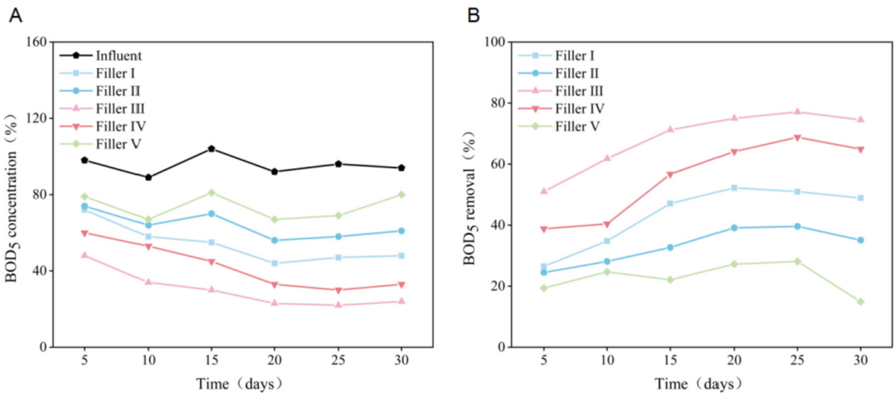

Fig. 3. The removal effect of different filter materials on BOD_5.

"slow upward" trend, which is due to the rough surface of these four filter media, which is more suitable for microbial growth. With the experiment, the biofilm gradually grows and stabilizes, which is beneficial to the degradation of organic pollutants. However, the biological ceramsite shows a trend of "fluctuating first, then declining", and the removal effect of BOD_5 is not good, which is due to the smooth surface of biological ceramsite, which is not suitable for microbial growth, resulting in the difficulty in forming biofilm, so the removal performance of organic pollutants is poor.

4 Conclusion

Five different filter media, red sandy soil, black volcanic rock, red volcanic rock, slag and biological ceramsite, were selected as the test materials of CRI system, and then the removal effects of different filter media on COD and BOD_5 concentrations in domestic sewage were investigated. The following conclusions can be drawn:

(1) Red volcanic rock has excellent removal efficiency of COD. The COD concentration of effluent is 43.8 mg/L, and the corresponding removal rate is 72.1%. The effluent quality can meet the irrigation standard of Class B vegetables in Farmland Irrigation Standard (GB5084–2005).
(2) Red volcanic rock has good removal effect on BOD_5. The concentration of BOD_5 in the effluent is 30.2 mg/L, and the corresponding removal rate is 74.4%, respectively. The effluent quality can meet the irrigation standard of Class A vegetables in Farmland Irrigation Standard (GB5084–2005).
(3) Red volcanic rock has outstanding removal ability for COD and BOD_5, the reasons are: 1) There are many adsorption sites on the surface of filter media, which have strong adsorption ability; 2) The surface is porous, which is suitable for microbial growth and reproduction, and is beneficial to the formation and stability of biofilm. Therefore, the adsorption of red volcanic rocks and the degradation of microorganisms jointly promote the removal of organic pollutants.

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