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Waste Brick as Constructed Wetland Fillers to Treat the Tail Water of Sewage Treatment Plant

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Abstract

Adopting the concept of "using waste to treat waste", the waste bricks will be used for constructed wetland filling. Integrated vertical-flow constructed wetland (IVCW) studied on the purification effect in influent water under three hydraulic loads (0.15, 0.25, 0.35 m/day). The results show that the waste bricks can be used as the carrier for the growth of the system biofilm, and have positive effects on the removal of pollutants in the influent water. Under three different hydraulic load conditions, the vertical flow of CWs can significantly reduce the load of water intake. In the low hydraulic load condition of 0.15 m/day, the average removal rates of chemical oxygen demand (COD), ammonia nitrogen (NH_3-N), total nitrogen (TN), and total phosphorus (TP) can reach 66.52%, 72.10%, 56.53% and 91.55% in this system, respectively. The influent pool on removal efficiency of pollutants was obviously higher than that of the upper pool, especially in the inlet surface 0–30 cm ranges. This research has achieved the effect of using "waste" to treat wastewater, which has strong practical significance and popularization value.

Keywords Constructed wetlands · Sewage treatment · Hydraulic loads · Waste bricks

With the rapid development of society, water resources and environmental problems are increasingly serious (Wu et al. 2015). Especially, the aggravation of water pollution has damaged people's health and sustainable economic development (Rousseau et al. 2004; Wu et al. 2014). Governments have also formulated policies and measures to reduce emissions and recycle sewage for this situation. Thus, some reasonable and useful techniques of sewage treatment has been widely studied and reported (Mohan et al. 2008; Chen et al. 2008; Hamid et al. 2019). At present, with the respect to the treatments of influent water from municipal sewage treatment plant, the researchers in various countries mainly investigate the following techniques: biological aerated filter (BAF), membrane bioreactor (MBR), biological activated carbon filtration technology (ACF) (Chen et al. 2009; ZHANG et al. 2010; Ivanov et al. 2013), and so on. However, these wastewater treatment technologies have high cost, high energy consumption and low treatment efficiency for organic pollutants, which are not fully applicable to the extensive application of wastewater treatment plant influent water treatment area. Therefore, it is very important to choose low cost and efficient alternative sewage treatment technology in developing regions.

For several decades, constructed wetlands (CWs) have been used as an ecological and green technology to treat waste waters (Wu et al. 2015; Ahmed et al. 2011). CWs offer a low-energy, land-intensive, and less operational-requirements alternative to conventional treatment systems, especially for small communities (Ahmed et al. 2011; Shen et al. 2015; Zaytsev et al. 2011). CWs have a great potential for the treatment of wastewater of different origin (Wang et al. 2016) such as domestic, agricultural and industrial wastewater (Liu et al. 2015). CWs have been successfully used to remove a wide variety of pollutants such as organic compounds, suspended solids, pathogens and metals (Dong et al. 2014). The filler is an important part and plays the most critical role in the treatment technology of CWs (Ji et al. 2016). Until now, there are many wetland fillers studied, such as zeolite, ceramsite, slag (Verlicchi and Zambello 2014), aluminum mud Zhao et al. 2011), composite materials (Zhao et al. 2019) etc. But the removal efficiency of nitrogen (N) and phosphorus (P) by these fillers were not

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high or the cost is high. Subsequently, the fillers of slag and gravel clods were extensively studied in CWs-sewage treatment process (BRASKERUD et al. 2000). The results show that the process has good phosphorus removal effect, but the removal rate of NH_3-N is low (An et al. 2014).

With the development of urbanization, a large number of construction waste is also produced, especially the waste brick accounts for 30%–50% of the construction waste (Bao et al. 2019). Because of the special composition of waste brick, it has the characteristics of light weight, multi-channel, large specific surface area, high surface roughness, and is used as artificial wetland filler (Shi et al. 2017). In the previous literature, the adsorption capacity and adsorption model of waste brick to pollution concentration, N and P were investigated systematically. However, many details have not been studied in depth, such as the influence of water flow process, filler size, filler method and contact mode on wastewater treatment effect, total nitrogen (TN) and total phosphorus (TP) removal rate, etc. (Yang et al. 2012).

In this work, the waste brick is used as the filler of CWs, and the reed and cattail which are common in northwest area are used as wetland plants. The purification effect of CWs system on secondary biochemical influent water and the change rule of pollutants along the process under different hydraulic load conditions are studied by the operation mode of "baffled vertical flow". The effects of filler size, laying mode and contact mode on the removal rate of chemical oxygen demand (COD), TN and TP in water treatment process were also studied. It was found that the baffle reactor increased the depth and hydraulic retention time of the device and improved the efficiency of pollutant treatment. The study provides theoretical basis and technical parameters for water treatment in the future.

Materials and Methods

In view of the fact that the actual effluent quality of some urban sewage treatment plants in Northwest of China is relatively high, the secondary effluent from a domestic sewage treatment plant in the campus is applied to this experiment as untreated water, and the water quality and analytic method are shown in Table 1 below:

The vertical flow constructed wetlands using waste brick as filler integrated sewage treatment system was built in 2016. The vertical flow constructed wetland with 0.9 m long, 0.44 m wide and 0.85 m high. The device is made of PVC plastic sheets and the wetland plants are composed of reeds and cattails. Detailed information on the integrated system can be found in Fig. 1. It is connected by two intermediate partitions and a connected bottom pool. In the two pools, waste bricks of different sizes (10–20 mm, 5–10 mm, 2–5 mm) are placed in the two pools, the height of the packaging layer is 5 m, and the upper layer is 4.8 m. The inlet of the system is made of DN20 mm porous tube, and the effluent is used for drainage. Reeds are planted on the surface of the wetland system. The upstream surface is mixed with reeds and cattails. The density is 78 plants/m^2. Both the dirty pool and the upper pool are set to three sampling ports from bottom to top, for a total of six sampling ports. The test system is carried out in the next 2 months.

The experimental control of the hydraulic loads is 0.15, 0.25 and 0.35 m/day. The effects of the pollutant removal in the flow type vertical flow artificial wetland under different hydraulic loads were studied from June to September 2016. The influent water, effluent water, and water samples respectively from various sampling points was tested every 2 days, using the measurement method "Water and Wastewater Monitoring and Analysis Method", and which issued by the Ministry of Environmental Protection of the People's Republic of China in 2002 (MEP), formerly State Environmental Protection Administration (SEPA). The COD was measured using the potassium dichromate method; NH_3-N was measured using Nessler's reagent colorimetric method; TN using the alkaline potassium persulfate digestion-UV spectrophotometric method; TP using the ammonium molybdate spectrophotometric method (Monitor 2002); The laboratory measures water temperature, DO and pH.

Results and Discussion

The surface morphology of the waste bricks was analyzed with the JSM-6701F cold field emission scanning electron microscope (FE-SEM), as shown in Fig. 2. Figure 2a shows the surface of waste bricks is uneven, providing favorable places for biological adhesion growth. The

Table 1 Artificial wetland water quality

Index	pH	COD (mg/L)	NH_3-N (mg/L)	TN (mg/L)	TP (mg/L)	WT (°C)	DO (mg/L)
Range	7.43–8.27	34.15–56.61	7.11–12.31	9.54–15.48	1.24–2.03	20°–26°	0.03–0.42
Standard deviation	0.20	5.03	1.41	1.08	0.21	3°	0.23

COD chemical oxygen demand, *NH_3-N* ammonia nitrogen, *TN* total nitrate, *TP* total phosphorus, *WT* water temperature, *DO* dissolved oxygen

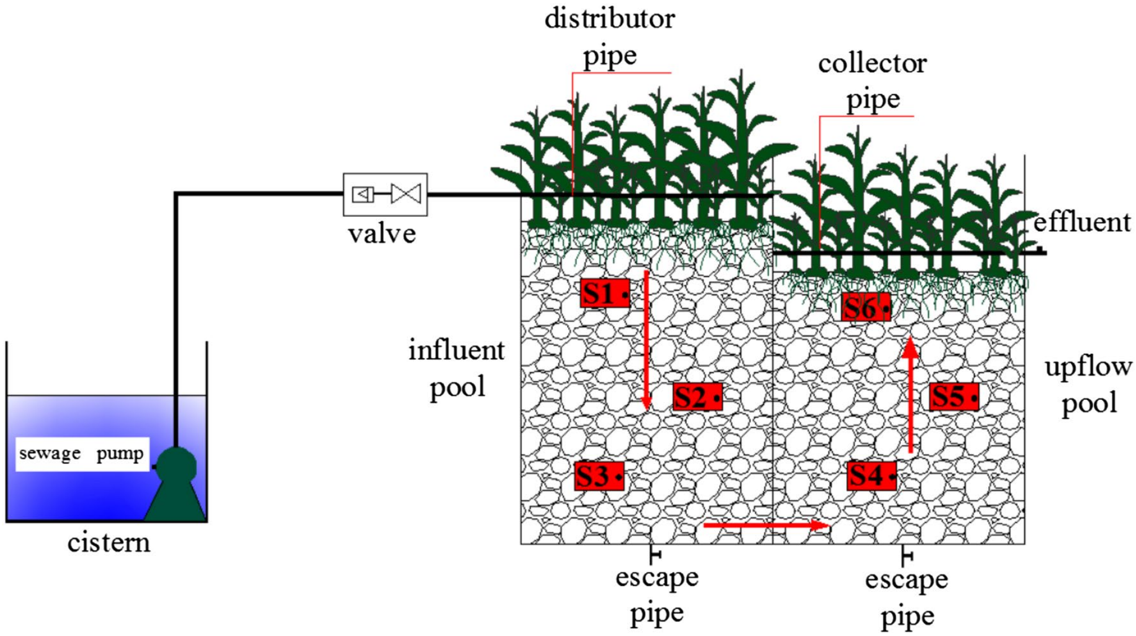

Fig. 1 Schematic diagram of baffled vertical-flow constructed wetland

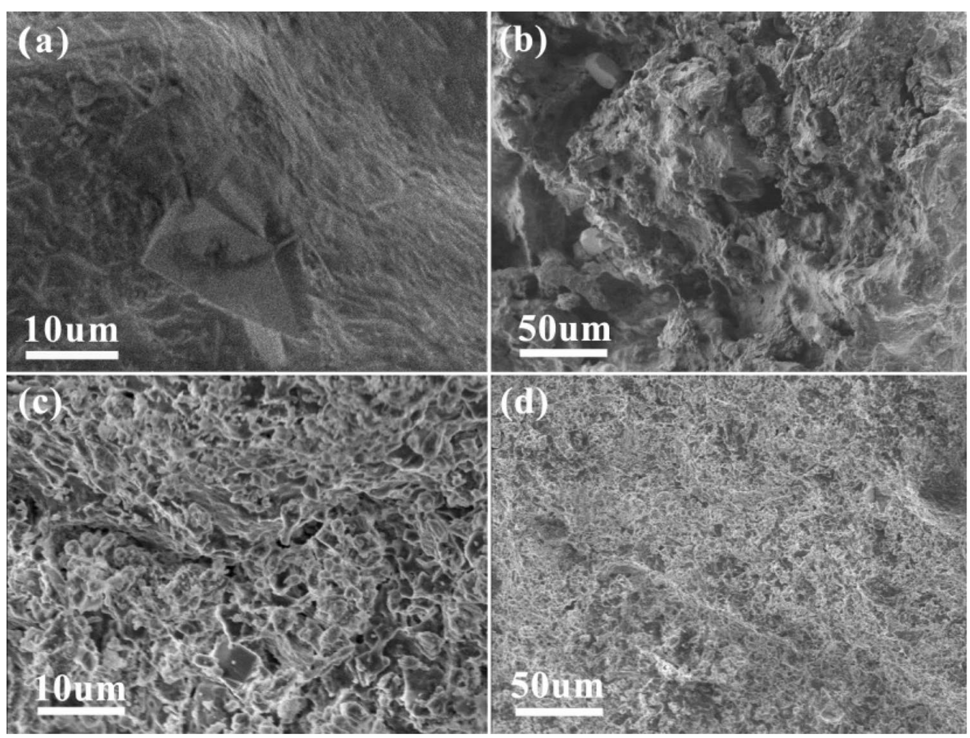

Fig. 2 SEM of broken bricks: **a**, **b** waste brick without biofilm, **c**, **d** waste brick with biofilm

surface of waste brick has many holes, which obviously increase the specific surface area of filler (as shown in Fig. 2b). A large number of biofilm structures grow on the surface of waste bricks, which are clearly observed in Fig. 2c, d. This indicates that waste bricks can provide sufficient space for the adhesion and growth of biofilm in the wetland system, which is conducive to the adsorption reaction of pollutants.

After the stable operation of the wetland system, water quality monitoring and data collection began on June 3, 2016. You can see from Fig. 3, the wetland system of effluent water remained above 60%, the removal rate of COD effluent

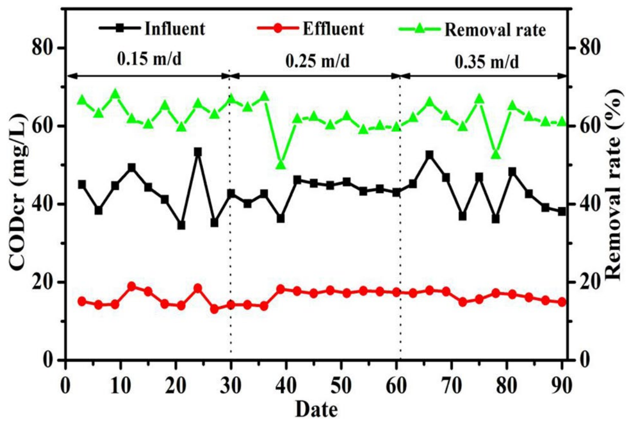

Fig. 3 Removal of COD under different hydraulic loads

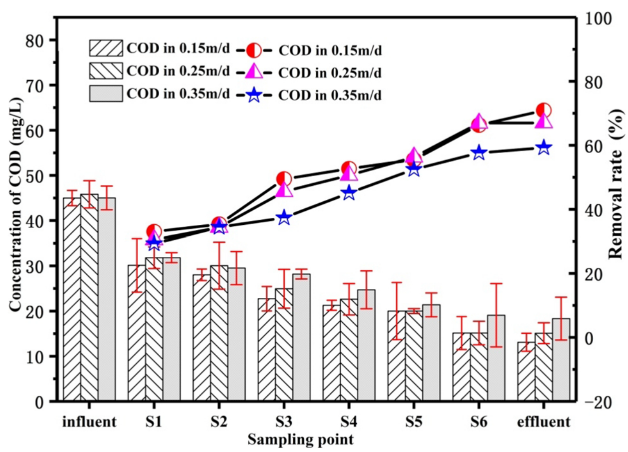

Fig. 4 The concentration variation of COD along with the experiment flow

are lower than the surface water environment quality standard "(GB 3838-2002) of III class water quality standards limit (20 mg/L), indicates that the system for the secondary biochemical COD of influent water has better removal effect, and the system has a certain ability to resist impact load. And in 0.15, 0.25, 0.35 m/days under three different hydraulic loading system of COD removal effect is stable, it shows that the hydraulic load effect on removal of COD is relatively small, it is similar to the findings of Ghosh and Gopal (2010). The main reasons for the above results are:(1) the concentration of water inlet COD was relatively low (the average is 42.89 mg/L), and the water intake organic matter could not easy to be used by microbes; (2) the waste bricks of wetlands contain organic matter, and the root system of wetland plants is decomposed, which resulted in the artificial wetland have a certain background COD concentration.

Under three different hydraulic loads, the concentration of COD in the wetland system decreased gradually (Fig. 4). Effluent water of COD concentration in inlet side has a rapid decline in process, and most of the organic matter has been removed in influent pool, the removal rate of COD in the influent pool reached 63.89%, 54.05%, and 54.05%, respectively, and the variation of COD under three kinds of hydraulic load along the similar trend. The due to the effluent water COD content is relatively low, the process of effluent water flow down most of the organic matter through the matrix (waste bricks), the adsorption of anaerobic–aerobic interception, plant roots, and oxygen and anaerobic microbial degradation were removed efficiently. When the sewage from the dirty pool to the upper pool, organic matter concentration is low and it leads to microbial activity is relatively low, and plant roots deterioration will also release of organic matter, so the removal rate curve is relatively flat. Weerakoon (Weerakoon et al. 2013) and others with gravel and slag for vertical flow wetland matrix composite is studied with the undercurrent of artificial wetland for sewage along the removal of COD in rule after the similar results, but the removal efficiency of COD is inferior to the system, it could be a test in wetland substrate-waste bricks, surface structure suitable to the growth of biofilm on the improvement of the influent water treatment system has a promoting effect (Table 2).

The removal of NH_3-N from artificial wetland mainly includes the absorption of plants, adsorption of the matrix, ammonia volatilization and nitrification of microorganisms (Lu et al. 2015). The effect of the wetland system on the removal of NH_3-N in secondary biochemical influent water is shown in Fig. 5.

As can be seen from Fig. 5, the wetland system maintains a better removal rate of NH_3-N in the influent water, and

Table 2 Methods and instruments for water quality analysis

No	Items	Detection method	Equipment
1	pH	Portable pH meter	PHS-3C type acidity meter
2	DO	Portable dissolved oxygen meter	JPB-607A dissolved O_2 Meter
3	COD	Rapid closed catalytic digestion	Lianhua COD rapid tester
4	NH_3-N	Nessler's reagent colorimetric method	722 Visible spectrophotometer
5	TN	Alkaline potassium persulfate digestion-UV spectrophotometric method	752 UV–Vis spectrophotometer
6	TP	Ammonium molybdate spectrophotometric method	722 Visible spectrophotometer

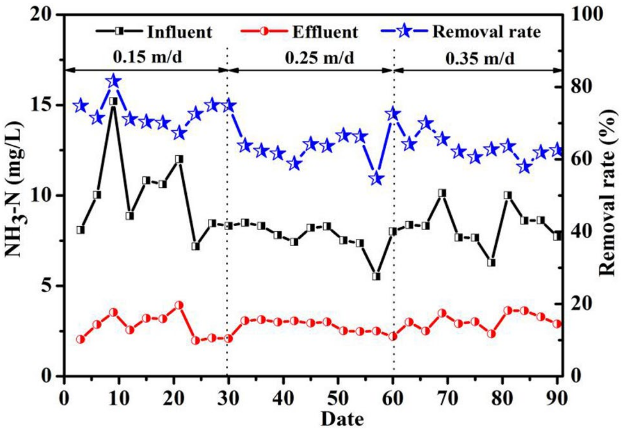

Fig. 5 Removal of NH_3-N under different hydraulic loads

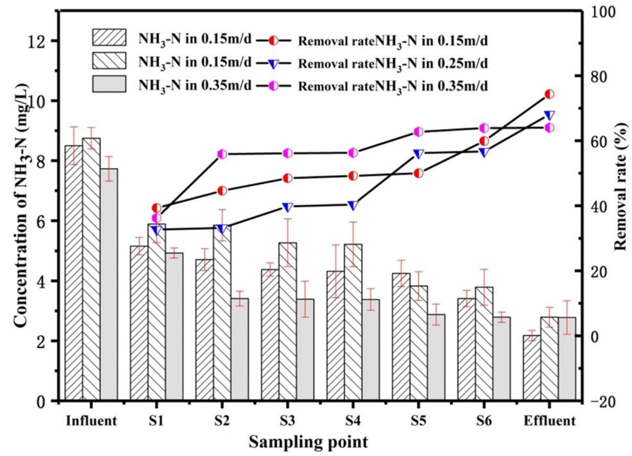

Fig. 6 The concentration variation of NH_3-N along with the experiment flow

the mass concentration of the water NH_3-N is lower than 3 mg/L. The average removal rate of NH_3-N was 72.10%, 64.03%, 62.88%, respectively. Under different hydraulic loads of 0.15, 0.25, 0.35 m/day, and the system's effect on NH_3-N removal decrease with the increase of hydraulic load (Fig. 5), The study shows that (Zheng et al. 2016), the main removal mechanism of NH_3-N in the artificial wetland system is the nitrification of microorganisms, and the lack of oxygen supply can be a limiting factor for the nitrification of submerged wetlands. In fold flow in vertical flow constructed wetland system, nitrification of oxygen by the DO into the water to carry (p = 0.9–3.2 mg/L) and with the root supply of wetland plants, the low dissolved oxygen state of the system has a certain limitation on oxygen consumption. On the other hand, with hydraulic load increases, the influent water in the wetland system of residence time shortened, thus ammonifier and ammonia nitrogen contact time shorten, nitration reaction caused by an inadequate system of NH_3-N purification efficiency decreases.

Figure 6 shows that the concentration of NH_3-N in the water inlet had a precipitous process, and the removal rate of NH_3-N was higher than that in the lower and middle layers. Sampling mouth S1 of NH_3-N removal rate accounted for 38.67%, 33.74%, and 35.47% of the total removal rate. The main reasons for the above results are: (1) during the test phase, was the flourishing period of the wetland plants (June to August), the plant roots of the developed wetland can assimilate part of the nitrogen while the root system is oxygenated; (2) the optimal pH of nitrification reaction was 7.0–8.2 (Lu et al. 2015). In the study, the water inlet pH value (7.84 + 0.53) was weakly alkaline in favor of the removal of ammonia nitrogen; (3) the larger than surface areas of the waste bricks are beneficial to the adsorption of ammonia nitrogen, and also provides the conditions for the nitrification of the root system. The whole system has gradually decreased along with the range of NH_3-N along the different hydraulic loads. Most NH_3-N in the influent water has been adsorbed and degraded in the downward pool, and the few remains are removed in the upper reaches. It shows that adsorbed the ammonia nitrogen of fillers are often quickly and reversible, by adsorption of ammonia nitrogen desorption role in wetland system, coupled with the bottom of the system and the upper pool of the anoxic environment has restrained the nitrification of NH_3-N. The combined effect of the two makes the removal of NH_3-N in the up-flow tank more gradual.

The removal of the wetland system depends on the synergistic effect of biological, physical and chemical reactions. In general, nitrification and denitrification are the main mechanisms of nitrogen removal (Zheng et al. 2016). When the hydraulic load are 0.15, 0.25, 0.35 m/day, the average of the total nitrogen removal in the system were 56.53%, 49.45%, and 56.53%, respectively, hydraulic load of the wetland system had a greater influence on the removal of total nitrogen, and reduce the hydraulic load in vertical flow constructed wetland system is an effective measure to improve an ability of removing nitrogen (as shown in Fig. 7). The system has a low TN removal rate for a total removal rate between 40% and 60%. The total nitrogen concentration in the water was much lower than the grade A standard of pollutant discharge standard of urban sewage treatment plant (GB18918-2002). The study shows (Xu et al. 2015), that the influent nitrogen form of the system will affect the removal rate of TN, in that the influent nitrogen form is mainly about NH_3-N, the removal rate is lower than that of the system which the influent nitrogen form is mainly about NO_3^--N. In addition, the lack of carbon sources will directly affect the removal rate of total nitrogen in CWs system (Zhang et al. 2018). There is a lower ratio of about influent carbon to nitrogen in this

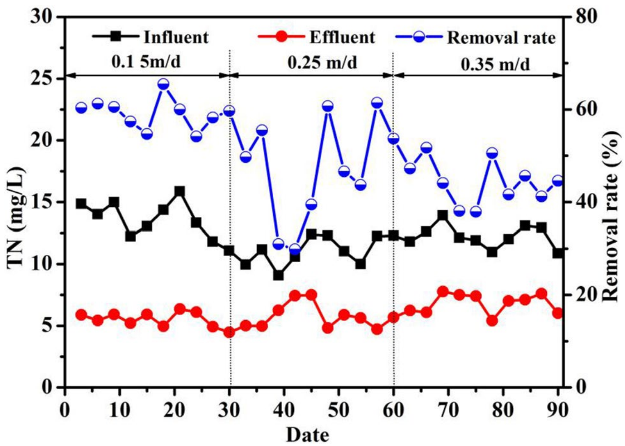

Fig. 7 Removal of TN under different hydraulic loads

experiment (C/N < 6), which may be an important factor in the system's low total nitrogen removal rate.

According to the Fig. 8 shows, under different hydraulic loading, the concentration of TN is obviously shown as a large decrease in the influent sink, while the concentration in the upper flow sink is relatively slow, and especially the reduction is obvious below 30 cm by the surface, and which have 51.33%, 39.45%, 49.11% of the total removal rate respectively. Main reasons: on the one hand, the roots of the wetland surface plants are growing, the number of microorganisms is large and the activities are strong, and the nitrogen is adsorbed and intercepted, then gradually converted into the N_2 and escaped system. On the other hand, as the influent water first enters the downstream pool for oxygen consumption; the DO concentration is low, which cannot provide a good nitrification environment. In addition, the study found that each removal of 1 mg NO_3^--N needs to consume COD 6.7–8.0 mg (Zhou et al. 2017). Denitrification is a process of energy dissipation, the lower carbon source in the upper flow sink limits good progress of denitrification, resulting in a lower contribution of the upper flow sink to the TN removal rate (Wu et al. 2012; Ying-Feng et al. 2001). Similar conclusions were obtained when used low-carbon nitrogen to pollute river water by using reed gravel bed artificial wetland, but the removal effect on pollutants is lower than that of this system, which indicated that waste bricks are beneficial to improve the removal rate of pollutants in this wetland system. Since the waste brick filler biofilm is more than the common filler biofilm, the TN removal rate is also 10% to 15% higher than that of the ordinary filler, and the system effluent TN concentration is lower.

Lantzke et al. (1999) found that under short-term operating conditions, the wetland system in phosphorus removal contribution is: matrix > microbes > aquatic plants. The effect of plant absorption on phosphorus removal is related to plant growth status, plant species, harvest frequency and time, water intake load and climatic conditions (Lu et al. 2017). Therefore, the main removal pathway of phosphorus in this wetland system is the substrate adsorption precipitation and plant assimilation absorption, and the adsorption and chemical precipitation of the matrix is dominant. The effect of the wetland system on TP removal in secondary biochemical influent water is shown in Fig. 9.

Under three kinds of hydraulic loads, 0.15, 0.25, 0.35 m/day, the system effluent TP concentrations were 0.15, 0.2, and 0.24 mg/L, respectively. It is lower than the standard water quality standard limit (0.3 mg/L) in "the Surface Water Environmental Quality Standard (GB 3838-2002)". It can be seen that the removal rate of TP was decreasing with the increase of hydraulic load, and the removal of phosphorus in the influent water was related to the hydraulic load. The lower hydraulic load was beneficial to the adsorption precipitation and assimilation absorption of phosphorus by waste bricks. However, increasing the hydraulic load would

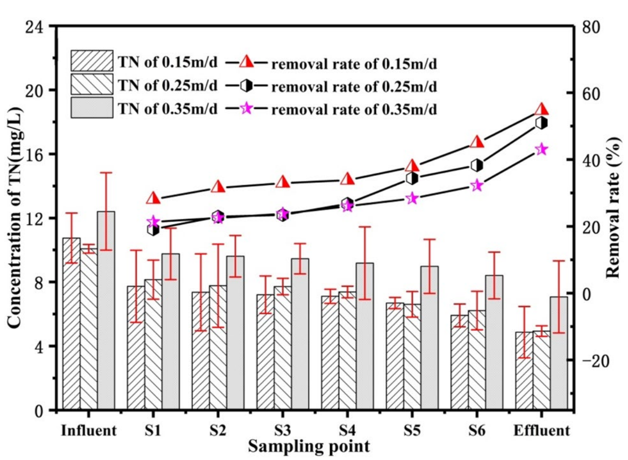

Fig. 8 The concentration variation of TN along with the experiment flow

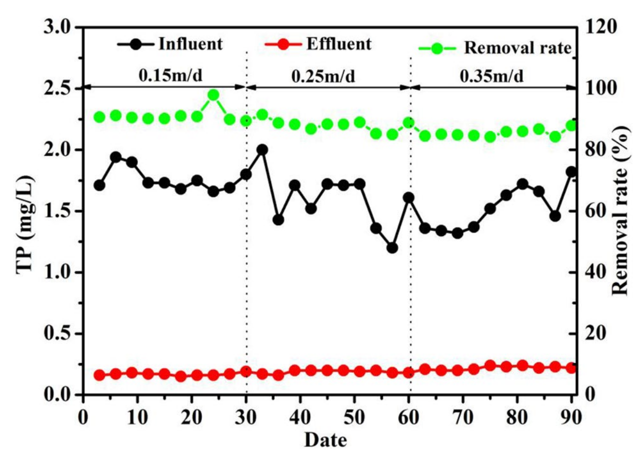

Fig. 9 Removal of TP under different hydraulic loads

shorten the stay time of the influent water in the wetland, causing the phosphorus in the secondary influent water not to be absorbed and transformed. On the other hand, under the condition of high hydraulic load, flushing of the substrate by the water stream may cause the phosphorus originally adsorbed on the surface of the substrate or plant roots to flush out of the system (Tang et al. 2012), and resulting in the TP removal rate decline. The wetland system has a good purification effect on TP, and the total removal rate of phosphorus can up to 90%. Compared with other wetlands with similar operating conditions, the removal rate of phosphorus is higher in this wetland, mainly due to the "coarse" porous structure of the waste bricks of wetland matrix that had well adsorption capacity for phosphorus. Since the waste brick filler biofilm is more than the common filler biofilm, the TP removal rate is also about 20% higher than that of the ordinary filler, and the system effluent TP concentration is lower.

Under different hydraulic load conditions, the TP concentration of wetland is decreasing along the course direction, and the change of removal rate curve is relatively smooth (Fig. 10). This may be due to the fact that the removal of phosphorus in the wetland system was mainly affected by the growth of vigorous reeds, the absorption of calamus and the adsorption precipitation of waste bricks, which are less affected by microbial activity and DO concentration. It can be seen from the figure that the TP concentration at the inlet end is rapidly reduced, and the TP removal rate of the influent pool is respectively reached 71.24%, 64.19%, and 56.16%, accounting for 81.54%, 74.85%, and 68.67% of the total system removal rate. This shows that the removal of total phosphorus in the baffled vertical flow constructed wetland mainly occurs in the influent pool. The TP concentration of the water inlet was rapidly decreased and the TP removal rate of the influent pool was 71.24%, 64.19%, and 56.16%, respectively, accounting for 81.54%, 74.85%, and 68.67% of the total removal rate in the system. This indicates that the removal of total phosphorus in the fold-flow vertical flow artificial wetland occurs mainly in the pool which the water downward.

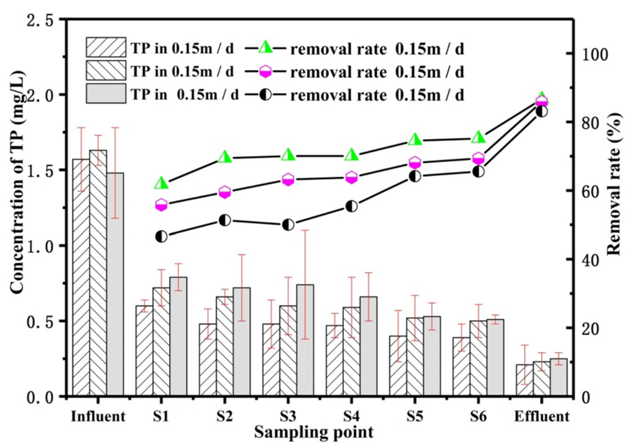

Fig. 10 The concentration variation of TP along with the experiment flow

In order to further show the advantages of waste bricks as fillers, we compared the advantages and disadvantages of different sewage treatment technologies and different CWs-fillers in detail (in Table 3). Obviously, the waste brick will have great application prospects and potential as constructed wetland fillers in the future. However, when the waste bricks are saturated by adsorption and the pollutant removal effect of the constructed wetland is greatly reduced, and the waste brick filler needs to be replaced. According to our later experiments, the waste brick filler can be replaced, and the waste brick is replaced about once a year to treat the affluent water."

Conclusion

In summary, the fold-flow vertical flow CWs system with waste bricks as filler showed high phosphorus removal capacity in the process of treatment of secondary biochemical influent water. The removal rate is 20% higher than the ordinary filler. The hydraulic load has a direct effect on the

Table 3 Comparison of sewage treatment process

Treatment technology	Advantage	Disadvantage	References
BAF	Small footprint, great capacity of treatment nitrogen and strong resistance to impact load	Heavy energy consumption, high cost	Cui et al. (2019), Abou-Elela et al. (2015)
MBR	Small footprint, great capacity of treatment N and P	Heavy energy consumption, high cost	Wang et al. (2019)
ACF	Great removal effect on trace pollutants and organic pollutants	Expensive construction and operation cost	Sbardella et al. (2018)
CWs			
Zeolite filler	Low cost	Low removal efficiencies of N and P	Strzemiecka et al. (2010)
Polymer biofilm filler	High removal efficiencies of N and P	High cost	Feng et al. (2015)
Waste brick filler	Low cost; high removal efficiencies of N and P	Short life cycle	This work

purification effect of the wetland pollutants, the removal rate of pollutants decreases with the increase of hydraulic load, (except COD), reducing the hydraulic load was conducive to reducing the concentration of water pollutants in the wetland system. Under different hydraulic loads, the removal of pollutants from the fold-flow vertical flow artificial wetland occurs mainly in the dirty pool, especially in the area of the wetland surface 0–30 cm. This indicates that the construction waste-waste brick is used as the filling of the flow type vertical flow CWs. This research has achieved the effect of using "waste" to treat waste water, which has strong practical significance and popularization value.

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References

Abou-Elela SI, Fawzy ME, El-Gendy AS (2015) Potential of using biological aerated filter as a post treatment for municipal wastewater. Ecol Eng 84:53–57

Ahmed G, Latifa B, Fabio M, Martin R (2011) Constructed wetland as a low cost and sustainable solution for wastewater treatment adapted to rural settlements: the Chorfech wastewater treatment pilot plant. Water Sci Technol A 63:3006

An W, Zhou X, Liu X, Chai PW, Kuznicki T, Kuznicki SM (2014) Natural zeolite clinoptilolite-phosphate composite Membranes for water desalination by pervaporation. J Membr Sci 470:431–438

Bao Z, Lu W, Chi B, Yuan H, Hao J (2019) Procurement innovation for a circular economy of construction and demolition waste: lessons learnt from Suzhou, China. Waste Manag 99:12–21

Braskerud CB, Lundekvam H, Krogstad T (2000) The impact of hydraulic load and aggregation on sedimentation of soil particles in small constructed wetlands. J Environ Qual 29:2013–2020

Chen ZM, Chen B, Zhou JB, Li Z, Zhou Y, Xi XR, Lin C, Chen GQ (2008) A vertical subsurface-flow constructed wetland in Beijing. Commun Nonlinear Sci Numer Simul 13:1986–1997

Chen J, Yao J, Bai YL (2009) Rural domestic wastewater treatment through anaerobism and artificial wetland. Agric Sci Technol (Engl). 10:158–161

Cui B, Yang Q, Zhang Y, Liu X, Wu W, Li J (2019) Improving nitrogen removal in biological aeration filter for domestic sewage treatment via adjusting microbial community structure. Bioresour Technol 293:122006

Dong QZ, Jinadasa KBSN, Gersberg RM, Yu L, Ng WJ, Tan SK (2014) Application of constructed wetlands for wastewater treatment in developing countries: a review of recent developments (2000–2013). J Environ Manag 141:116–131

Feng L, Yang G, Zhu L, Xu X, Gao F, Mu J, Xu Y (2015) Enhancement removal of endocrine-disrupting pesticides and nitrogen removal in a biofilm reactor coupling of biodegradable *Phragmites communis* and elastic filler for polluted source water treatment. Bioresour Technol 187:331–337

Ghosh D, Gopal B (2010) Effect of hydraulic retention time on the treatment of secondary effluent in a subsurface flow constructed wetland. Ecol Eng 36:1044–1051

Hamid KIA, Sanciolo P, Gray S, Duke M, Muthukumaran S (2019) Comparison of the effects of ozone, biological activated carbon (BAC) filtration and combined ozone-BAC pre-treatments on the microfiltration of secondary effluent. Sep Purif Technol 215:308–316

Ivanov I, Ren L, Siegert M, Logan BE (2013) A quantitative method to evaluate microbial electrolysis cell effectiveness for energy recovery and wastewater treatment. Int J Hydrogen Energy 38:13135–13142

Ji ZH, Feng CL, Wu XF, Zhou SY, Huang HM (2016) Research progress on filler application and purification mechanisms in constructed wetland wastewater treatment system. Chin J Ecol 8:35

Lantzke IR, Mitchell DS, Heritage AD, Sharma KP (1999) A model of factors controlling orthophosphate removal in planted vertical flow wetlands. Ecol Eng 12:93–105

Liu R, Zhao Y, Doherty L, Hu Y, Hao X (2015) A review of incorporation of constructed wetland with other treatment processes. Chem Eng J 279:220–230

Lu S, Pei L, Bai X (2015) Study on method of domestic wastewater treatment through new-type multi-layer artificial wetland. Int J Hydrogen Energy 40:11207–11214

Lu D, Chen Q, Liu P, Xia Z, Wang H, Zhou Q, Dong X, Wu Z (2017) Phosphorus removal performance and biological dephosphorization process in treating reclaimed water by Integrated Vertical-flow Constructed Wetlands (IVCWs). Bioresour Technol 243:204–211

Mohan SV, Mohanakrishna G, Ramanaiah SV, Sarma PN (2008) Simultaneous biohydrogen production and wastewater treatment in biofilm configured anaerobic periodic discontinuous batch reactor using distillery wastewater. Int J Hydrogen Energy 33:550–558

Monitor PASE (2002) Monitor and analysis method of water and wastewater. Chinese Environmental Science Publication House, Beijing

Rousseau DPL, Vanrolleghem PA, Pauw ND (2004) Model-based design of horizontal subsurface flow constructed treatment wetlands: a review. Water Res 38:1484–1493

Sbardella L, Comas J, Fenu A, Rodriguez-Roda I, Weemaes M (2018) Advanced biological activated carbon filter for removing pharmaceutically active compounds from treated wastewater. Sci Total Environ 636:519

Shen Z, Zhou Y, Jia L, Yu X, Rong C, Wu F (2015) Enhanced removal of nitrate using starch/PCL blends as solid carbon source in a constructed wetland. Bioresour Technol 175:239–244

Shi X, Fan J, Zhang J, Shen Y (2017) Enhanced phosphorus removal in intermittently aerated constructed wetlands filled with various construction wastes. Environ Sci Pollut Res 24:1–11

Strzemiecka B, Voelkel A, Kasperkowiak M (2010) Characterization of zeolites as potential new generation fillers in abrasive articles. Physicochemical properties of zeolites and their interactions with resins. Colloids Surf A 372:80–85

Tang ZR, Wen Y, Zhou Q (2012) Research on the phosphorus removal mechanisms and approaches in various horizontal subsurface flow constructed wetlands. Adv Mater Res 573–574:599–604

Verlicchi P, Zambello E (2014) How efficient are constructed wetlands in removing pharmaceuticals from untreated and treated urban wastewaters? A review. Sci Total Environ 470–471:1281–1306

Wang Q, Xie H, Ngo HH, Guo W, Zhang J, Liu C, Liang S, Hu Z, Yang Z, Zhao C (2016) Microbial abundance and community in subsurface flow constructed wetland microcosms: role of plant presence. Environ Sci Pollut Res 23:4036–4045

Wang H-C, Cui D, Han J-L, Cheng H-Y, Liu W-Z, Peng Y-Z, Chen Z-B, Wang A-J (2019) A2O-MBR as an efficient and profitable unconventional water treatment and reuse technology: a practical study in a green building residential community. Resourc Conserv Recycl 150:104418

Weerakoon GMPR, Jinadasa KBSN, Herath GBB, Mowjood MIM, Bruggen JJAV (2013) Impact of the hydraulic loading rate on pollutants removal in tropical horizontal subsurface flow constructed wetlands. Ecol Eng 61:154–160

Wu JQ, Wang M, Wu J, Tang H (2012) Treatment of polluted river water using surface flow constructed wetlands in Xinyi River Floodplain. Adv Mater Res 396–398:1909–1913

Wu S, Kuschk P, Brix H, Vymazal J, Dong R (2014) Development of constructed wetlands inperformance intensifications for wastewater treatment: a nitrogen and organic matter targeted review. Water Res 57C:40–55

Wu H, Jian Z, Ngo HH, Guo W, Zhen H, Shuang L, Fan J, Hai L (2015) A review on the sustainability of constructed wetlands for wastewater treatment: design and operation. Bioresour Technol 175:594–601

Xu Q, Hunag Z, Wang X, Cui L (2015) *Pennisetum sinese* Roxb and *Pennisetum purpureum* Schum. as vertical-flow constructed wetland vegetation for removal of N and P from domestic sewage. Ecol Eng 83:120–124

Yang Y, Wang ZM, Liu C, Guo XC (2012) Enhanced p, n and c removal from domestic wastewater using constructed wetland employing construction solid waste (csw) as main substrate. Water Sci Technol 66(5):1022–1028

Ying-Feng L, Shuh-Ren J, Tze-Wen W, Der-Yuan L (2001) Effects of macrophytes and external carbon sources on nitrate removal from groundwater in constructed wetlands. Environ Pollut 119:413–420

Zaytsev I, Mander Ü, Lõhmus K, Nurk K (2011) Enhanced denitrification in a bioaugmented horizontal subsurface flow filter. Ecol Eng 37:1050–1057

Zhang L, Zhang L, Liu Y, Shen Y, Liu H, Xiong Y (2010) Effect of limited artificial aeration on constructed wetland treatment of domestic wastewater. Desalination 250:915–920

Zhang L, Sun Z, Jia X, Wu J, Cheng S (2018) Nutrient removal, biomass accumulation and nitrogen-transformation functional gene response to different nitrogen forms in enhanced floating treatment wetlands. Ecol Eng 112:21–25

Zhao XH, Zhao YQ, Kearney P (2011) Transformation of beneficially reused aluminium sludge to potential P and Al resource after employing as P-trapping material for wastewater treatment in constructed wetland. Chem Eng J 174:206–212

Zhao M, Wang S, Wang H, Qin P, Yang D, Sun Y, Kong F (2019) Application of sodium titanate nanofibers as constructed wetland fillers for efficient removal of heavy metal ions from wastewater. Environ Pollut 248:938–946

Zheng Y, Wang XC, Dzakpasu M, Yuan G, Zhao Y, Xiong J (2016) Performance of a pilot demonstration-scale hybrid constructed wetland system for on-site treatment of polluted urban river water in Northwestern China. Environ Sci Pollut Res 23:447–454

Zhou X, Wang X, Zhang H, Wu H (2017) Enhanced nitrogen removal of low C/N domestic wastewater using a biochar-amended aerated vertical flow constructed wetland. Bioresour Technol 241:269–275