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Performance of a coupling device combined energy-efficient rotating biological contactors with anoxic filter for low-strength rural wastewater treatment

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A B S T R A C T

In order to meet the requirements of decentralized sewage treatment in rural China, a source-sorted treating method was proposed, including a black water pre-treating anaerobic baffled reactor (ABR), an anoxic filter (ANF), a novel multi-stair waterwheel driving rotating biological contactors (ms-wdRBCs) and constructed wetlands (CW). The ms-wdRBCs were utilized to post-treat mixture of digested black water and raw grey water with the ANF. Key parameters of ANF/ms-wdRBCS were identified founded on the nutrient removal performance, especially nitrogen removal, for further application in the project. Besides, the ANF/ms-wdRBCs coupling device was operated 10 weeks at the optimum parameters to confirm its performance on contamination removal. The coupling device performed well on chemical oxygen demand (COD), total nitrogen (TN), and ammonia (NH_4^+-) removal. When running under 150% reflux ratio, 1 h HRT of each-stair wdRBC and 7.11 h HRT of ANF, the removal efficiency of COD, TN, NH_4^+- and total phosphorus (RTP) were 88.40 ± 2.16%, 52.33 ± 3.80%, 88.14 ± 2.30% and 34.11 ± 7.00%, respectively. The NH_4^+-/ NO_3^-- concentration ratio of effluent was approximately 3 which was certificated to be beneficial to plants growth in CW. Although the removal efficiency of TP was only 34.11 ± 7.00%, the phosphorus was partly retained to contribute to plants growth in CWs. Overall, the entire four-part system achieved outstanding pollutant removal efficiencies, while the selected plants in CW also gained benefits back. Low construction and operating cost, simple management and easy maintenance of the system ensure the application in rural areas.

1. Introduction

World widely, severe environmental problems have been caused by the influx of human-induced nitrogen and phosphorus(Conley et al., 2009; Tong et al., 2017). It has been reported globally that discharged domestic sewage causes terribly environmental pollution in rural areas, especially in developing countries(Massoud et al., 2009). Non-point sources are significant sources of nutrients in rivers in eastern China. Tong, etc. (Tong et al., 2016) reported that non-point sources contribute 36% of the riverine TN discharge loading and 63% of the TP loading in the Yangtze River. In order to ameliorate the rural environmental conditions and avoid eutrophication, great efforts have been made to explore appropriate rural domestic sewage treating methods. Bio-eco technology combined systems are considered as the most common options for rural domestic sewage treatment(Kavanagh and Keller, 2007).

Common treating methods choose to deal with the mixed decentralized sewage, ignoring the contrasting characteristic of grey water (GW) and black water (BW), which resulted in resource and energy wasting. The problem would be magnified in treatment for low-strength sewage especially. In general, BW (originates from the toilets, including water, urine, faeces and toilet paper) contains the main part of organic load(Paulo et al., 2013) and GW (originates from bath, shower, sinks, kitchen and laundry) retains low contaminant concentration(Li et al., 2009). Besides, GW discharges a much larger quantity than BW roughly(Li et al., 2009), despite that quantity ratio of BW and GW ranged due to local economic conditions. Thus, treating sewage sorted from the source means an

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important step for domestic sewage treatment. Oppositely, there were minority of researches treating BW and GW respectively in rural area nowadays. Inspired by the above points, a combined system, which separated domestic sewage from the source was proposed for Chinese rural area. Four sections were contained in the system, including anaerobic baffled reactor (ABR); anoxic filter (ANF); multi-stair waterwheel driving rotating biological contactors (ms-wdRBCs) and constructed wetland (CW). The BW and GW were divided when collecting. The BW was pre-treated by the ABR and then the pre-treated BW and raw GW were mixed in the next sections. Due to the changeable quantity and quality of BW by time, the ABR was supposed to digest macromolecule organics in BW to avoid large water quality fluctuations. The anoxic and aerobic sections were constructed as a reflow system which means the effluent of ms-wdRBCs would partly reflux to the ANF. The reflow system was expected to oxidize most of the ammonia-nitrogen and remove part of the total nitrogen (TN) as well as total phosphorus (TP). Chemical oxygen demand (COD) was also expected to be low concentration in the effluent of ms-wdRBCs. Reserved nitrogen and phosphorus served as the essential nutrients for plants growth in CW. Meanwhile, effluent of the CW ought to be with low concentration through the treatment of plants and substrates.

It has been proved that the multi-stage structure with a continuous flow configuration provides outstanding dissolved oxygen supply with low energy consumption(Liang et al., 2010; Wang et al., 2011; Wu et al., 2013). And many evidences suggest that RBCs perform well for decentralized sewage on land area, maintenance, energy etc.(Dutta et al., 2007; Hiras et al., 2004). Thus, a novel device combined RBCs with the multi-stage structure was proposed to gain advantages in numerous aspects. Furthermore, waterwheels were connected with disks to replace motors for driving the disks to rotate which was conductive to energy conservation. The novel unit was named multi-stair waterwheel driving rotating biological contactors (ms-wdRBCs). Oxygen was captured mainly from three kinds of modes, including atmospheric reoxygenation, reoxygenation from water dropping and discs rotation. Multiple reoxygenation modes were assumed to produce ranged dissolved oxygen (DO). The novel structure of ms-wdRBCs would also save more land area and energy than regular RBCs or other kinds of mechanical aerators. Reticulated polyurethane sponge padding (RPSP) was added under disks in each stair of wdRBC. RPSP possessed a porosity more than 97% and a specific surface area greater than 1000 m^2/m^3. The excellent data ensured the space utilization for microbial growth and DO concentration difference between the surface and the inside.

There is a general view that anoxic-aerobic combined systems are effective methods for removing nitrogen by nitrification and denitrification(Ge et al., 2014; Ruiz et al., 2006). This article will focus on the "ANF/ms-wdRBCs" coupling device of the combined system considering the significance of nitrogen for domestic sewage treatment. The objectives of this study were to identify optimal key parameters of "ANF/ms-wdRBCs" and evaluate its performance on low strength rural domestic sewage (mixed sewage of anaerobic treated BW and raw GW) treatment under the optimal parameters, especially focused on nitrogen removal and conversion.

2. Materials and methods

2.1. Set-up of reactor experiments

Fig. 1 shows the flow chart of the whole bio-eco system. The experiments focused on the coupling device, including anoxic filter (material PVC, volume 160 L) and ms-wdRBCs (material PVC). 8 outlet pipes were set on ranged height for adjusting HRT of ANF. ANF were packed almost 40% with vertical combined packing to retain sludge and provide growth space for microorganisms. The ms-wdRBCs contained 3-stair wdRBCs (volume 9 L each) and one effluent collection tank (ECT, volume 3 L). Height difference among each wdRBC stair was maintained at 0.6 m. Every stair wdRBC was divided to 2 parts, named discs area (15 discs with 150 mm diameter) and waterwheel area (1 waterwheel with 150 mm diameter), respectively. The bottom part of discs areas was packed 20% with RPSP. Discs and waterwheels' submergence were both 40%. When running, flow rate of the circulating diving-water was adjusted at 200 ml/min and the rotation speed of discs was between 4 and 8 r/min.

2.2. Wastewaters and inoculum

ABR and ANF were inoculated with sludge from the secondary sedimentation tank in a municipal sewage plant. Ms-wdRBCs was started without seed-sludge, and got plentiful biofilm after continuously 1-month operation. BW influent was consisted of half toilet wastewater from teaching building in southeast university (Wuxi, Jiangsu, China) and half synthetic water (COD: glucose, sucrose, starch; TN and NH_4^+-: ammonium chloride, ammonium bicarbonate, urea; TP: potassium dihydrogen phosphate, dipotassium phosphate). GW influent was consisted of half wastewater from a canteen and dormitories in southeast university and half synthetic water. One-month monitoring of the water quality of the real separated domestic wastewater was operated. The quality of synthetic water for GW and BW was adapted according the average measured data. The influent of ms-wdRBCs was consisted of ABR digestion effluent and raw GW influent, quantity ratio of them was 1:3.6–1:7.2.

2.3. Experimental operating

Batch assays were performed to estimate the coupling device's pollutant removal in ranged HRT and reflux ratio to search optimum operating parameters. According to some reports on rural sewage treatment, HRT and reflux ratio ranges were determined preliminarily (Li and Lu, 2017; Wu et al., 2013). Influence of reflux ratio was estimated in run 1. TN、NH_4^+-、COD removal efficiencies under different reflux ratios (RR) (0, 50, 100, 150, 200, 250, 300%) were evaluated while wdRBC's HRT (HRT_{wdRBC}, HRT of each-stair wdRBC) and ANF's HRT (HRT_{ANF}) were kept at 40 min and 7.11 h, respectively. Influence of HRT_{ANF} was estimated in run 2, TN、NH_4^+-、COD removal efficiencies under different HRT_{ANF} (6.67 h, 7.11 h, 8.89 h, 10.67 h) were evaluated while HRT_{wdRBC} and RR were kept at 40 min and 150%, respectively. Influence of HRT_{wdRBC} was estimated in run 3, TN、NH_4^+-s、COD removal efficiencies under different HRT_{wdRBC} (30 min, 40 min, 60 min, 80 min) were evaluated while HRT_{ANF} and RR were kept at 7.11 h and 150%, respectively. For these three runs, the device was remained 4 days for each specific condition and the water qualities were measured every day at the last 3 days to get the average data. A duration of steady-state operation under optimum condition was lasted for 10 weeks in run 4, and contaminant concentrations in influents and effluents were monitored every 2 days. Temperatures during the whole experiments were between 15 and 32 °C.

2.4. Analyses

Concentration of COD, NH_4^+-N, NO_2^--N, NO_3^--N, TN and TP were measured quantitatively according to standard method(Nº, 2006). DO were measured with DO meter (YSI-DO200, YSI, Yellow Springs, OH, USA).